SPI-M-O: Summary of modelling for scenarios for COVID-19 autumn and winter 2021-22

Date: 13th October 2021

Summary

1. There are two principal sources of uncertainty determining epidemic trajectories to March 2022: behaviour and the rate at which vaccine-acquired immunity wanes. The first of these, "behaviour", determines the rate of transmission and has three components: contact rates (i.e. how many people each person interacts with per day), precautionary behaviour (for example, face masks), and critically the networks that are formed. The waning of immunity is apparent in the data, but its rate of decrease and the lowest level of vaccine effectiveness are both unknown.

2. It will take **both** a rapid increase in transmission rates and repeated waning of protection from vaccination to lead to hospital admission levels in the order of magnitude of those seen in January 2021. Unless both these eventualities occur, or a new variant of concern emerges, it is highly unlikely that such levels of hospital admissions will be reached in the coming autumn and winter.

3. If protection from vaccination does not wane much further than already observed, then hospital admission rates are unlikely to get significantly higher than those currently seen. If booster vaccinations are effective, have a high uptake, and do not wane over the timescales considered here, then hospital admission rates are also unlikely to get much higher than currently seen.

4. There are complex sensitivities around the interactions of how behaviour changes over time, the waning of immune protection and the associated booster vaccination programme and, as a result, the timing of the next peak is uncertain. This could vary from "it has already happened" to "late into 2022". There are several unknowns that may resolve over the coming months, such as the longer-term effects of waning of vaccine protection and the effectiveness of boosters.

5. Many of the scenarios modelled have an extended period of time with a high number of hospital admissions. Even if peak admission levels remain well below those of January 2021, this could still put health and care settings under significant pressure, particularly if this coincides with high numbers of patients with other respiratory infections, which have not been modelled here.

6. SPI-M-O highlighted the invaluable contributions of the ONS COVID-19 Infection Survey (CIS) to understanding the epidemic dynamics, particularly in the face of changes over time in testing behaviour. Lateral flow testing is an important component of both individual risk management and population surveillance of incidence.

Importance of data streams in the long run

7. High quality data and surveillance of COVID-19 have been key to understanding and responding to the epidemic waves of the pandemic. Some data that are critical for individuals and the immediate epidemic response, however, are less useful for longer term surveillance of the dynamics during the transition to endemicity. For example, testing data is key to allow people to isolate and for their contacts to be traced, and to alert the local level public health response. Testing, tracing, and isolation remain critical in controlling the epidemic. Heterogeneities and time-trends in test-seeking behaviour, however, mean that it is often difficult to infer with confidence the underlying true infection dynamics purely from the observed number of confirmed cases.

8. Since its development, the ONS COVID-19 Infection Survey (CIS) has been an invaluable data stream to understand the progression of the epidemic. SPI-M-O's consensus view is that, for understanding the dynamics of SARS-CoV-2, the CIS, will in the longer term remain the critical viral surveillance tool because of its stable denominator. This data stream is vital alongside counting hospitalisations and deaths for understanding the transmission dynamics.

9. Were the study to continue throughout 2022, it would allow ongoing COVID-19 risks to be foreseen, support identification of subsequent waves that challenge healthcare if there is significant waning immunity and/or viral evolution, and optimisation of future vaccination use. It is conceivable that, if something in the wider situation changed (for example, a new variant, waning, international context, a coinfection issue) and the CIS was discontinued, there would be suddenly an immense need to restart the study.

10. SPI-M-O highlighted that daily testing of contacts of cases with lateral flow tests (LFTs), can have a comparable effect to quarantining contacts in terms of potential impact on transmission[1], and so is an important mechanism for controlling transmission; possibly more so than is currently achieved. At higher prevalence levels, positive LFTs are more likely to be true COVID-19 cases and so can be as informative as PCR tests, limiting the additional value of such follow up tests. PCR tests, however, are needed for subsequent

[1] SPI-M-O: Statement on daily contact testing; SAGE 83 11th March

sequencing and are important for community surveillance (ONS CIS), and in health and care settings. Identification of emerging variants of concern, for example, requires PCR tests.

Modelling autumn and winter 2021-22

11. SPI-M-O has considered the results from three academic groups, who have independently modelled future scenarios of the COVID-19 epidemic over the coming autumn and winter, from mid-October 2021 into 2022. These do not consider non-COVID-19 infections nor any pressures that these other diseases may exert on health and care settings. These models assume that:

    - No social distancing measures are re-imposed and that behaviours do not change in response to prevalence.
    - The delta variant remains dominant.
    - The booster vaccination programme is not extended to further groups than those currently announced.

    A summary of the key assumptions that underpin these models can be found in Appendix 1 and with more detail in the accompanying modelling documents. A fourth modelling group, the University of Bristol, has used an alternative analytical approach to estimate the total epidemic potential.

12. These trajectories are not predictions or forecasts, but indicative scenarios as the timings and scale of any future peaks remain highly uncertain; they could happen later, last longer, or be flatter than those illustrated here. Modelling cannot capture the effect of any future fine timescale trends at local level, therefore actual trajectories are expected to be less smooth and more volatile than the modelling here suggests.

13. All modelling groups currently assume waning of protection from vaccination is homogeneous across age groups, despite emerging evidence that this is not the case with more adverse outcomes in those who are older or more vulnerable. Once boosters are considered, however, it is unclear what impact this heterogeneity of waning may have on this modelling and whether the overall effect may be positive or negative. Groups do account for natural boosting, i.e. where a vaccinated individual is infected with to SARS-CoV-2 that strengthens their immune response.

14. At a national level, SARS-CoV-2 prevalence in England has remained very high, yet broadly flat for a sustained period, although there have been shifts in prevalence in different age groups over this time and spatial heterogeneity remains evident. Whilst social distancing rules and guidance have lifted, testing and isolation of cases as well as testing

and tracing of contacts remain in place. The CoMix study estimates that contacts continue to be relatively low, with substantial levels of home working and, as yet, there has been little wintery weather. As a result, transmission remains significantly below the levels expected from a full return to pre-pandemic winter behaviour.

15. One key difference between the modelling groups' scenarios depends on their estimation of how much potential remains until reaching pre-pandemic behaviour levels. London School of Hygiene and Tropical Medicine (LSHTM) use mobility data, which suggests levels that are much closer to "normal" than that inferred through Warwick's precautionary behaviour metric, Φ. As a result, LSHTM's scenarios are generally more optimistic than those from Warwick.

16. There is also a danger of subtleties in behaviour and mixing not being captured in this modelling. Increases in transmission around the time of the Euro 2020 football matches were not visible in data sources, such as CoMix or Google mobility. If similar were to happen again as mixing increases and behaviour returns to pre-pandemic levels, it is possible that these modelling results may be too optimistic. This is particularly a danger if the final return to "normal" connects different population groups that are not currently mixing with each other; mobility and contact numbers may not change much but the resulting network effects may boost transmission. The mid-winter festive period usually sees very different mixing behaviour that could have a similar effect to the Euro 2020 football matches.

General conclusions

17. SPI-M-O agrees that, while further waves of infection are still expected, it is highly unlikely that hospital admissions in the coming autumn and winter will reach peak numbers similar to last winter, without both rapid and repeated waning of vaccination protection **and** a quick return to pre-pandemic levels of behaviour.

18. From the latest SPI-M-O modelling, the short-term trajectories to end of 2021 are mainly driven by behaviour, whereas any future peaks in 2022 are mainly due to the speed and level of waning and associated booster regimes. Currently how fast waning of protection may occur or to what level it may fall to is unknown. There is time, however, for such information to be collected and to build understanding of, for example, long-term booster effectiveness and population heterogeneity in waning, and gather more details on which aspects of immune protection wane.

19. There are complex sensitivities around the interactions of how behaviour changes over time, the waning of immune protection and the associated booster vaccination programme. These relationships can be further exacerbated by seasonality, although this has a smaller

impact than either behaviour or waning. To reduce or possibly even rule out the risk of a large COVID-19 wave over the next six months or so, behaviour is the key factor that can be influenced. Booster vaccinations (who gets them and when) may also be very important in future years. Other factors are biological unknowns that are not controllable, such as the patterns of waning of vaccine- and infection-derived immune protection and the effectiveness of boosters.

20. If behaviour change to normal or pre-pandemic levels are encouraged to be only *gradual*, then there is both the potential to avoid a large wave as well as providing more time to find answers to potential future problems, gather more understanding (for example, what does waning post-booster vaccination look like), and prepare for future waves where necessary (for example, make evidence-based decisions on boosters for younger age groups and those who are not vulnerable). More evidence will emerge over the coming months and 2022, both from the UK and worldwide.

21. The pattern of transmission in England since 19th July 2021 has been very unexpected. There have been considerable changes in prevalence by age group and in different communities, but the overall level of admissions has changed very slowly and has been essentially constant. This requires some additional feedback, or self-regulation in the population, and the exact mechanism is unknown, but is likely to involve testing and self-isolation within different networks. Given the unknown mechanism, it would be advisable to keep the current policies and access to testing in place.

22. Many of the modelled scenarios have an extended period of time with a high number of hospital admissions. Even if peak admission levels are well below those of January 2021, this could still put hospitals under pressure, particularly if there were also high numbers of patients with other respiratory infections. These other infections have not been included in the modelling. Easy access to rapid testing would remain important in such a situation.

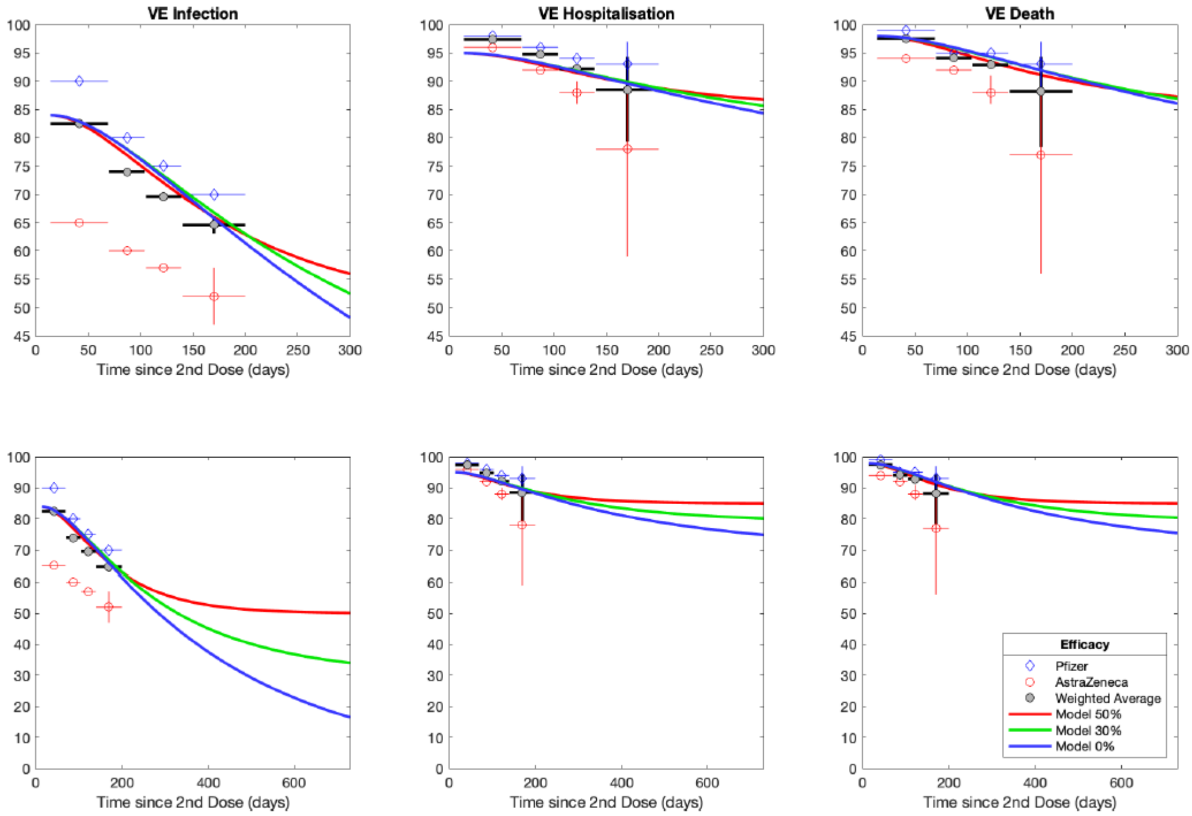
University of Warwick

23. Warwick has conducted multi-way sensitivity analyses that consider three key factors:

- How rapidly behaviour changes, with scenarios where this returns to pre-pandemic levels at different time points between December 2021 and June 2022.
- The effect of booster doses: either that the third dose increases protection against infection to 90% (slightly higher than after two doses), after which it wanes at a similar rate to two doses; or that protection against infection from the third dose is 100% and does not wane. Broadly speaking, Warwick's view is that these can be considered as being best- and worst-case scenarios, with the most likely outcome between the two.

- Thirdly, while data are available about the extent to which vaccines' effectiveness has waned so far, it is not known how much further it can fall. Warwick models scenarios where vaccines continue to wane so that long-term two-dose effectiveness asymptotically reaches a) 50% against infection and 85% against hospitalisation/death (little further or low waning); b) 30% against infection and 79% against hospitalisation/death (intermediate waning); or c) 0% against infection and 70% against hospitalisation/death (high waning). These three different waning scenarios are illustrated in Figure 1.

Figure 1: Waning immunity in the Warwick model against infection (left), hospitalisation (middle) and death (right). Shapes show Public Health England's (now UK Health Security Agency) preliminary estimates (blue diamonds, Pfizer; red circles, AstraZeneca; grey circles, weighted average) and lines show modelled scenarios (from top to bottom: red, low waning; green, intermediate waning; blue, high waning). Please note that the same data are plotted twice with different x and y axes in the two rows.



24. The trajectory of hospital admissions for these scenarios are given in Figure 2. Each row represents a given length of time it takes to return to pre-pandemic behaviours (top to bottom; December 2021, February 2022, April 2022, and June 2022); the two columns represent sustained immunity after the first booster (left) or the repeated waning of boosters (right); and each colour represents different waning scenarios for vaccine protection.

25. In scenarios where there is little further waning (Figure 2, blue lines), the number of hospital admissions gradually declines from current levels over the course of a few

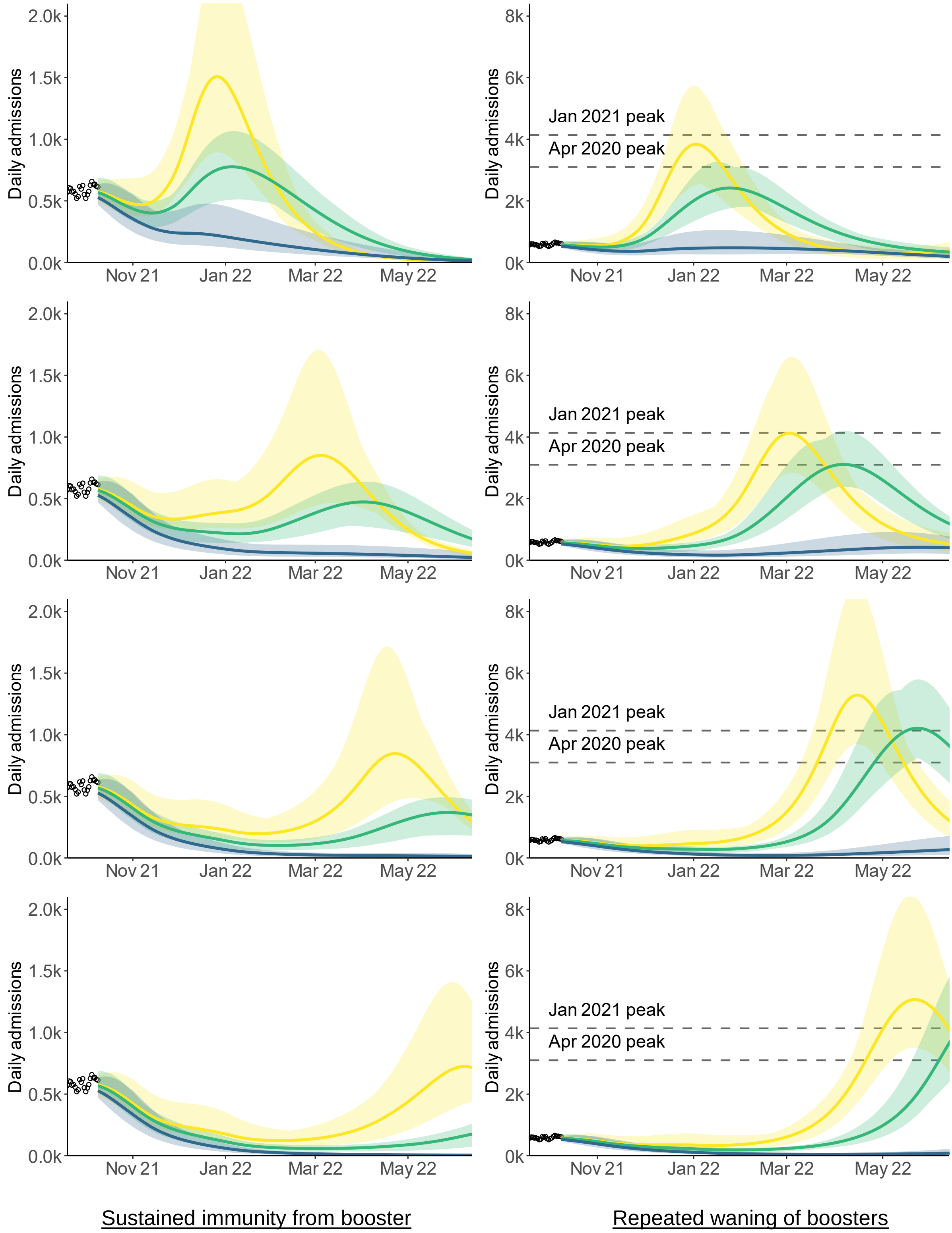
months, even if behaviour returns to pre-pandemic levels by December 2021 (Figure 2, top row).

26. With intermediate (Figure 2, green lines) or high waning (Figure 2, yellow lines), a similar pattern of gradually declining admissions is seen for the next few months in scenarios where behaviour takes longer to return to “normal”. Later, a combination of waning immunity, behaviour change, and seasonality (which is assumed to be 10% variation in transmission, peaking in mid-February in Warwick’s base case) results in a further wave. The timing of this wave is highly uncertain with modelled peaks ranging from January to May 2022.

27. Similarly, the peak in admissions of the epidemic waves in the high and intermediate waning scenarios is uncertain (Figure 2, yellow and green lines respectively), but they are generally considerably lower than in January 2021. Only in the scenarios with high levels of waning from both second *and* booster doses (Figure 2, right hand column) is this level of hospital admissions approached; in scenarios where the booster dose does not wane over the time scales modelled, the peak is seldom higher than that of summer 2021.

28. Warwick also performed sensitivity analyses on the extent of seasonality. As expected, scenarios with more seasonality have larger waves in winter, but those with less seasonality have the potential for larger ones in summer 2022, if booster vaccination protection has significantly waned by then. Nevertheless, the peaks in hospital admissions remain broadly within the range shown in Figure 2.

Figure 2: Projected dynamics of daily hospital admissions in England from Warwick's model. Three different assumptions on waning protection from vaccination (low waning, blue; intermediate waning, green; high waning, yellow) are shown in each plot. Four different relaxation rates to pre-pandemic behaviours are considered in each row (top by December 2021; second by February 2022; third by April 2022; bottom by June 2022). The absence (left) and presence (right) of repeated waning of booster effectiveness are shown in columns. 95% prediction intervals (shaded band) and means (solid line) of the distribution of model runs are shown. Please note the different y axis scales between the columns.



London School of Hygiene and Tropical Medicine (LSHTM)

29. LSHTM has also focused on three similar uncertainties:

- How rapidly mobility and behaviour changes, with four scenarios: where this returns to pre-pandemic levels over three weeks, three months, six months, or remains at current levels.
- The waning of vaccine protection and boosters. Three scenarios are considered: a) where the percentage reduction in protection observed by Public Health England (PHE)[2] up to 21st September[3] is applied to vaccine effectiveness estimates ("less waning"), b) where protection wanes to 75% of those levels ("moderate waning") or c) where protection wanes to 50% of those levels ("more waning").
- Uptake of boosters is 50% in 50-year olds and over, 90% in 50-year olds and over, or the programme is extended to all ages and uptake reaches a uniform 90%.

30. As with the work of other groups, it should be noted that the credible intervals given in the model's outputs represents an average over many runs. The timing of peaks from the individual model runs could be considerably earlier or later, or higher or lower than those depicted here.

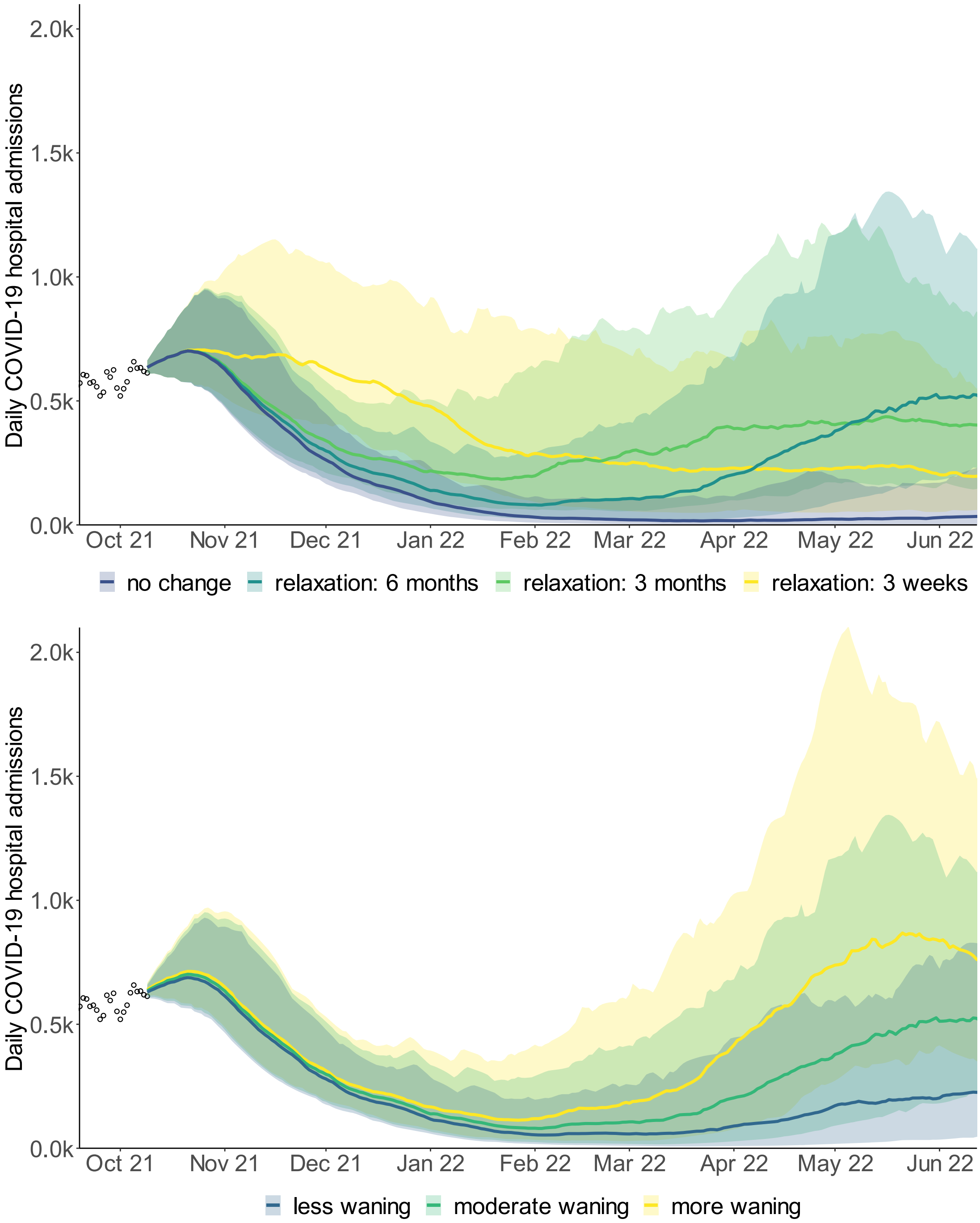
31. In most scenarios LSHTM see little to no further increase in hospital admissions in the short term, even with a rapid return to near-normal behaviours (Figure 3, top plot, yellow line). With a slower change in mobility (Figure 3, top plot, green and blue lines), there is a drop in admissions followed by another wave of infection. Its timing is highly dependent on the combination of the extent of waning and the speed of behaviour change, but in most modelled scenarios this peak happens well into 2022.

32. Over autumn and winter, LSHTM's results are not particularly sensitive to their assumption on waning vaccine protection (Figure 3, bottom plot). This only starts to become a more significant factor as 2022 progresses. The timing of the subsequent peak is highly uncertain and depends on the interaction with behaviour changes.

[2] Now the UK Health Security Agency (UKHSA)
[3] Vaccine effectiveness and duration of protection of Comirnaty, Vaxzevria and Spikevax against mild and severe COVID-19 in the UK | medRxiv

Figure 3: LSHTM's results for daily hospital admissions in England for different mobility scenarios (top) where return to pre-pandemic levels of mobility happens over three weeks (yellow), three months (pale green), six months (dark green), or with current levels maintained (no change, blue). Moderate waning is assumed.

The same daily hospital admissions for different scenarios of waning vaccine protection are also shown (bottom) which assume less waning (blue), moderate waning (green) or more waning (yellow). Here mobility is assumed to return to pre-pandemic levels over six months. 90% credible intervals (shaded band) and medians (solid line) of the distribution of model runs are shown.



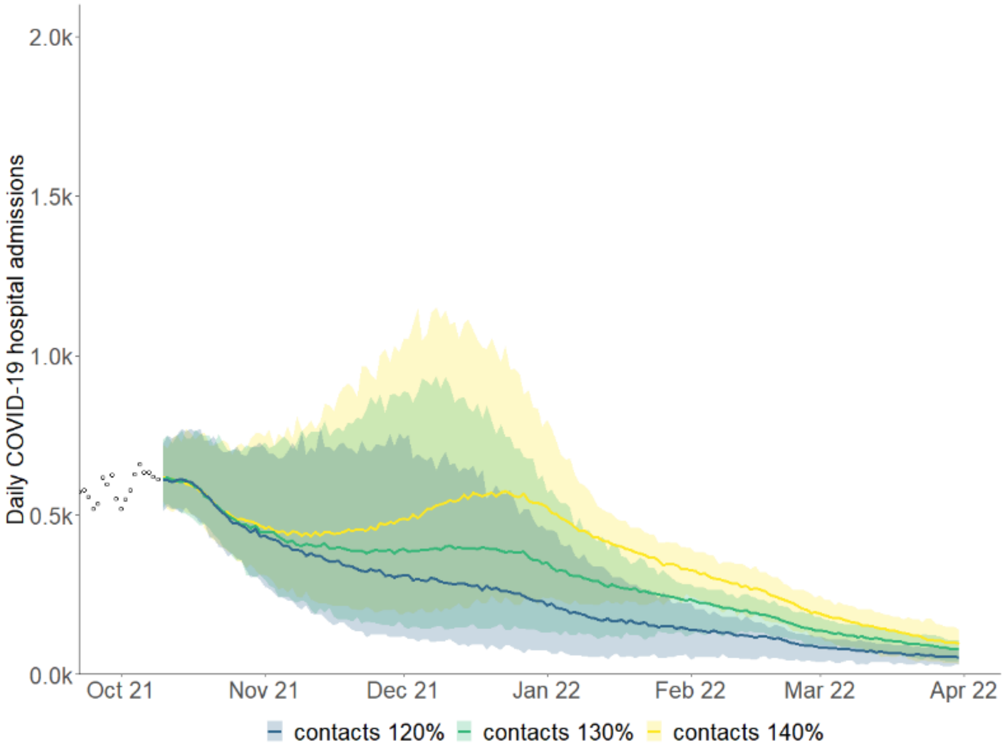
Imperial College London

33. Imperial College London have focused their sensitivity analyses on two parameters:

- Three scenarios for how contact rates change between now and 1st December 2021, which increase from their current level by 20%, 30%, or 40%. The last of these is broadly equivalent to reaching pre-pandemic levels.
- Two scenarios for booster vaccine effectiveness. In their "central" vaccine effectiveness scenario, a third dose increases protection against hospital admission and death to 99%, and against infection to 92%. In their "pessimistic" scenario, they assume the third dose provides 90% protection against hospital admission, 95% against death, and 78% against infection.

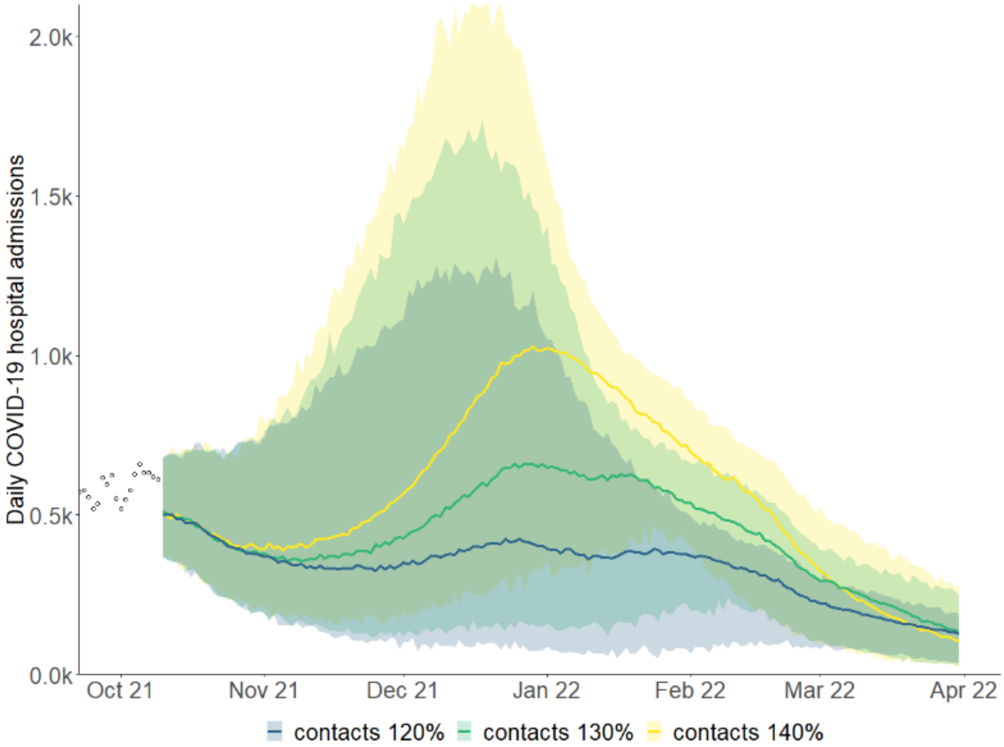
34. Imperial's results follow broadly similar patterns as those from Warwick and LSHTM. As would be expected, with booster vaccines increasing protection against hospitalisation to 99%, in the central vaccine effectiveness scenario (Figure 4) the credible intervals for the three scenarios range from a gradual decline in hospital admissions from their current values, to an increase up to slightly over 1,000 admissions per day.

Figure 4: Daily hospital admissions in England in the Imperial College model with central vaccine effectiveness assumptions, assuming transmission increases by 20% (blue), 30% (green), or 40% (yellow) of current levels. 95% credible intervals (shaded band) and medians (solid line) of the distribution of model runs are shown.



35. In the lower booster vaccine effectiveness scenario (Figure 5), there are more hospital admissions. Even in this scenario with an increase in contacts by 40%, however, the number of hospital admissions remains well below January 2021 levels.

Figure 5: Daily hospital admissions in England in the Imperial College model with pessimistic vaccine effectiveness assumptions, assuming transmission increases by 20% (blue), 30% (green), or 40% (yellow) of current levels. 95% credible intervals (shaded band) and medians (solid line) of the distribution of model runs are shown.



University of Bristol

36. Modellers from Bristol have used an alternative approach building on “ready reckoners”[4]. These take an analytical approach to estimating the size of the future epidemic and possible future reproduction numbers, depending on levels of mixing, the extent to which mitigation measures (such as testing, tracing, and isolation) reduce transmission, and future vaccination. Although this method cannot show how the epidemic could look at a given time, it can estimate the maximum plausible reproduction number and the *total* future mortality over the next wave. This approach is a valuable check for models that have more complex assumptions built in.

---

[4] SPI-M-O: Comments on social distancing, SAGE 38 20th May 2020; SPI-M-O: Comments on Social Distancing Measures, SAGE 43 22nd June 2020; SPI-M-O: Statement on population case detection, SAGE 56 10th September 2020; SPI-M-O: Consensus statement on COVID-19 and underlying papers University of Bristol and PHE: COVID-19 Reckoners with Vaccination – Update and PHE: Ready reckoners under vaccination based on POLYMOD contact surveys, SAGE 86 8th April 2021; JUNIPER Consortium: Transitioning from non-pharmaceutical interventions to vaccination to control COVID-19 transmission, SAGE 93 7th July 2021.

37. Using the assumption that no mitigation measures are in place, and the presence of antibodies reduces mortality by 95%, infection by 70% and transmission by 60%, this method estimates that the effective reproduction number would be in the range of 1.1 to 1.6 were pre-pandemic levels of mixing returned to with current vaccination levels. This is broadly in line with other modelling described here; while there is still potential for considerable epidemic growth, it is much lower than pre-vaccination, even accounting for the emergence of the Delta variant.

38. Under these assumptions, the addition of a booster programme and vaccination for 12- to 15-year olds (with 65% uptake) reduces the reproduction number to 0.9-1.3.

Appendix 1: Model assumptions

Parameter values shown here are for the Delta variant. Parameter values for Alpha and other sensitivities are given in the accompanying papers.

Parameter	Imperial College London			LSHTM		
		Central	Waning (central)		Central	Waning (central)
Vaccine reduction in risk of infection	AZ 1 dose	33%		AZ 1 dose	43%	
	AZ 2 dose	58%	43%	AZ 2 dose	63%	36%
	PF/MD 1 dose	33%		PF/MD 1 dose	62%	
	PF/MD 2 dose	85%	67%	PF/MD 2 dose	80%	45%
Vaccine reduction in risk of onward transmission if infected (additional to transmission reduction due to reduced infection risk)	AZ 1 dose	40%		AZ 1 dose	5%	
	AZ 2 dose	40%	40%	AZ 2 dose	27%	17%
	PF/MD 1 dose	40%		PF/MD 1 dose	24%	
	PF/MD 2 dose	40%	40%	PF/MD 2 dose	37%	24%
Vaccine reduction in risk of symptomatic disease	AZ 1 dose	33%		AZ 1 dose	52%	
	AZ 2 dose	58%	43%	AZ 2 dose	65%	37%
	PF/MD 1 dose	33%		PF/MD 1 dose	62%	
	PF/MD 2 dose	85%	67%	PF/MD 2 dose	81%	46%
Vaccine reduction in risk of hospitalisation admission	AZ 1 dose	80%		AZ 1 dose	84%	
	AZ 2 dose	90%	77%	AZ 2 dose	93%	57%
	PF/MD 1 dose	85%		PF/MD 1 dose	92%	
	PF/MD 2 dose	95%	89%	PF/MD 2 dose	96%	67%

Parameter	Warwick				
	For dose 2:	Central	Waning (low)	Waning (med)	Waning (high)
Vaccine reduction in risk of infection	AZ	70%	50%	30%	0%
	PF/MD	85%			
Vaccine reduction in risk of onward transmission if infected (additional to transmission reduction due to reduced infection risk)	AZ	30%	20%	20%	20%
	PF/MD	30%			
Vaccine reduction in risk of symptomatic disease	AZ	70%	55%	35%	10%
	PF/MD	90%			
Vaccine reduction in risk of hospitalisation admission	AZ	95%	85%	79%	70%
	PF/MD	95%			

<table>
<tr><th>Parameter</th><th>Imperial College London</th><th>LSHTM</th><th>Warwick</th></tr>
<tr><td>Vaccine reduction in risk of death</td>
<td><table>
<tr><th></th><th>Central</th><th>Waning (central)</th></tr>
<tr><td>AZ 1 dose</td><td>80%</td><td></td></tr>
<tr><td>AZ 2 dose</td><td>95%</td><td>85%</td></tr>
<tr><td>PF/MD 1 dose</td><td>85%</td><td></td></tr>
<tr><td>PF/MD 2 dose</td><td>95%</td><td>89%</td></tr>
</table></td>
<td><table>
<tr><th></th><th>Central</th><th>Waning (central)</th></tr>
<tr><td>AZ 1 dose</td><td>95%</td><td></td></tr>
<tr><td>AZ 2 dose</td><td>95%</td><td>59%</td></tr>
<tr><td>PF/MD 1 dose</td><td>92%</td><td></td></tr>
<tr><td>PF/MD 2 dose</td><td>96%</td><td>66%</td></tr>
</table></td>
<td>For dose 2:<table>
<tr><th></th><th>Central</th><th>Waning (low)</th><th>Waning (med)</th><th>Waning (high)</th></tr>
<tr><td>AZ</td><td>98%</td><td rowspan="2">85%</td><td rowspan="2">79%</td><td rowspan="2">70%</td></tr>
<tr><td>PF/MD</td><td>98%</td></tr>
</table></td></tr>
<tr><td>Rollout speed (England basis)</td><td colspan="3">Per Cabinet Office scenario for Imperial and Warwick:
Future vaccine rollouts follow a Cabinet Office Scenario with an average of 1.3 million booster doses administered per week for the vulnerable and over 50-year olds and an average of 200,000 first doses offered per week for those aged between 12 and 15.

In addition, Warwick assume a low level of first doses (approximately 10,000 per day) continue to be administered.

LSHTM rollout as above for 12- to 15-year olds. Other doses administered based on measured delays between first and second doses, the start of the booster programme and assumed average duration of second dose protection.</td></tr>
<tr><td>Coverage achieved (primary doses)</td>
<td><table>
<tr><th>Age group</th><th>Central</th></tr>
<tr><td>12 - 15</td><td>50%</td></tr>
<tr><td>16+</td><td>Per actuals</td></tr>
</table></td>
<td><table>
<tr><th>Age group</th><th>Central</th></tr>
<tr><td>12 - 19</td><td>70%</td></tr>
<tr><td>20+</td><td>Per actuals (PHE/UKHSA first dose uptake as of 3rd October)</td></tr>
</table></td>
<td><table>
<tr><th>Age group</th><th>Central</th></tr>
<tr><td>12 - 15</td><td>75%</td></tr>
<tr><td>16 - 24</td><td>75%</td></tr>
<tr><td>25+</td><td>Per actuals</td></tr>
</table></td></tr>
<tr><td>Coverage achieved (boosters)</td><td>As for dose 2 for eligible groups.</td><td>90% of eligible people aged 50 and over.

Other sensitivities considered:
• 50% of eligible people aged 50 and over
• 90% of eligible people (all ages)</td><td>90% of those aged 50 and over who have received a second dose.</td></tr>
<tr><td>Waning immunity</td><td>Waning of natural immunity, with average time to loss of protection of six years (central) or three years (pessimistic).

Exponential waning of vaccine-derived immunity, with mean of 20 weeks (after second dose).</td><td>Waning of natural immunity by 15% over one year.

Central (moderate) waning of vaccine-derived immunity as shown above. Sensitivities for “less” and “more” waning provided in accompanying paper.</td><td>Waning of natural immunity not included over timescale modelled.

Three scenarios for asymptotic waning of vaccine-derived immunity considered, as shown above.</td></tr>
</table>

Parameter	Imperial College London	LSHTM	Warwick
Impact of booster vaccine	Increased vaccine effectiveness relative to dose 2, with central (above) and pessimistic assumptions as given in accompanying paper. No waning of booster effectiveness over timescale modelled.	Vaccine effectiveness as dose 2.	Two scenarios considered: • Pessimistic: increased vaccine effectiveness relative to dose 2, with protection against infection at 90% which then wanes in a similar manner to two doses • Optimistic: boosters generate complete protection, with protection against infection at 100%, over timescale modelled
Behaviour	Scenarios considered for increases in contacts by 20%, 30% or 40% by December 2021.	Central scenario assumes return to pre-pandemic mobility levels within six months. Other sensitivities considered include retaining mobility levels at current levels and returning to baseline levels within three weeks or three months.	Scenarios considered in which precautionary behaviour returns to pre-pandemic levels by dates between December 2021 and June 2022.
Seasonality	20% peak to trough variation in transmission.	20% peak to trough variation in transmission.	10% peak (February) to trough (August) variation in transmission in central scenario. Other scenarios of 20%, 30% and 40% considered.