Estimates concerning COVID-19 vaccine coverage among University of Bristol students in Teaching Block 1 of the Academic Year 2021/22, and the expected effect on the 'R' number.

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Abstract

We use publicly available data on the COVID-19 vaccine rollout in the UK, and recent research on COVID-19 vaccine hesitancy in the UK, to estimate the proportion of University of Bristol students who will have been vaccinated in time for the start of Teaching Block 1 of the Academic Year 2021/2022. We then use this (combined with some other publicly available data, and some straightforward mathematical modelling), to estimate the likely effect on the reproduction number R, compared to in Teaching Block 1 of the Academic Year 2020/2021, under a range of possible scenarios for vaccine effectiveness against the strains that will be circulating. Under what we think is the most likely scenario, we estimate that the reproduction number R among University of Bristol students on campus during Teaching Block 1 of the Academic Year 2021/2022 is likely to be 20-40% lower than it was in Teaching Block 1 of the Academic Year 2020/2021. There is quite a lot of uncertainty in this estimate. In particular, it assumes that the UK is able to prevent (during Autumn 2021) the widespread community transmission of new variants that can escape the vaccines currently being distributed. We caution that the latter possibility (that new variants, which can escape the vaccines currently being distributed, start to circulate widely during the Autumn), unfortunately cannot be ruled out. The UK government hopes to distribute 'boosters' to protect against new variants, distributing these to high-risk groups from September 2021 onwards [1], but such 'boosters' are not likely to be distributed to those of student age (excepting the highly clinically vulnerable), during Autumn 2021. Our estimates should therefore be treated with caution: they correspond, roughly, to what we think is the most likely situation (where widespread vaccine escape is not taking place in the UK). So they are not (e.g.) a 'reasonable worst-case scenario'. Our estimates suggest that some caution is advisable, with regard to arrangements for students, and teaching, during the Academic Year 2021/2022.

Estimates on the vaccine rollout

Our first observation is that, if the UK continues to vaccinate its adult population at the rate seen so far (since 11th January 2021), and keeps to the 12-week limit on the gap between first and second doses (as per the MHRA authorisation), then we would expect all UK residents aged 18 and above to have been offered both first and second doses of a COVID-19 vaccine by 19th August 2021, implying that the vaccine would take full effect in such individuals by 2nd September 2021 (14 days after the second dose), i.e., 26 days before the start of Teaching Block 1. This is close to a best-case scenario: the UK's vaccination programme could well be delayed by export restrictions/bans on vaccines and vaccine-components (e.g., by the export restrictions announced on 25th March 2021 by India, affecting at least 5 million doses of the Oxford/AZ vaccine which had been scheduled for delivery to the UK), but it is quite possible that the UK government will find a way to circumvent this export restriction and future export restrictions, without incurring a delay of more than 26 days.

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According to the UK Government COVID-19 vaccination dashboard [14], the total number of first doses which were reported delivered in the UK by 10th January 2021, was 2,289,831. The total number by 24th March 2021 (i.e., 73 days later), was 28,991,188. This yields an average of $(28,991,188 - 2,289,831)/73 = 365,772$ first doses delivered, per day, for the period 11th January 2021 to 24th March 2021. There are approximately 52,384,000 individuals in the UK aged 18 and above (ONS, 2018 estimate). Assuming that 365,772 first doses are delivered per day (on average) from 25th March until the end of May, this implies that it will take a further $(52,384,000 - 28,991,188)/365,772 = 64$ days from 25th March, to vaccinate the remaining UK residents aged 18 or above, with the first dose. In other words, all UK adults would have been offered their first dose by 27th May 2021. Assuming that the UK government is able to keep to the 12-week limit between first and second doses (as per the MHRA authorisation), this implies that all UK adults would have been offered their second dose by 19th August 2021. Assuming that the vaccine reaches its full effectiveness 14 days after the administration of the second dose, this implies that, for all UK adults not refusing the vaccine, it will have taken full effect by 2nd September 2021: 26 days before the start of Teaching Block 1.

Of course, this is an optimistic scenario, in that it assumes the UK government will be able to circumvent the effect of export-controls on vaccine and vaccine-components, imposed recently (and those which may be imposed in the future), by other countries. For example, two days ago, on 25th March 2021, the government of India instructed India's Serum Institute (the largest vaccine manufacturer in the world), to halt exports, citing the accelerating second wave of infections in India; the Financial Times [7] was told that these measures could last as long as two to three months. These export restrictions are likely to affect the shipment of at least five million doses of the Oxford/AstraZeneca vaccine, that had been scheduled for delivery to the UK. This, on its own, would not delay the UK programme by as long as 26 days. Indeed, the UK government has ordered more than 400 million vaccine doses [9], and even if the UK government is unable to make arrangements in time to replace any of the five million doses blocked from export this week, it would delay the administration of first doses by only $5,000,000/365,772 = 14$ days, well within the 26 days' leeway before the start of Teaching Block 1. Of course, future (more severe) export restrictions may be imposed, by other countries as well as by India. On 25th March 2021, the European Commission placed before EU leaders a proposal to impose restrictions on the export of vaccines or vaccine-components to highly-vaccinated countries. EU leaders declined to back this proposal [2], but tensions remain, and the imposition of export restrictions by EU countries cannot be ruled out. Equally, the UK government, and the pharmaceutical companies it has contracts with, may find ways of circumventing such export restrictions, if they are imposed.

Estimates on vaccine refusal

From henceforth, in view of the arguments above, we assume (a little optimistically, but it is still a reasonable and plausible assumption) that all UK adults (i.e., those aged 18 and above), will have been offered a vaccine (both first and second doses) in time for the vaccine to take full effect by the start of Teaching Block 1. Of course, not everyone who is offered a vaccine, will take up this offer; to take account of this, we need estimates on vaccine hesitancy in the UK.

Research by King's College London [5], carried out in November 2020, found that 8% of UK residents (aged between 16 and 75) who were surveyed, would 'definitely not' take up the offer of a COVID-19 vaccine, even if it was available to anyone who wanted it. A further 6% said they would be 'not at all likely' to take up such an offer; a further 9% said they would 'not be very likely' to take it up, and a further 7% said they 'did not know'. We assume, crudely, that 80% of those who said they would be 'not at all likely' to take up the offer, will indeed refuse the vaccine, and that 60% of those who said they would 'not be very likely' to take up the offer, will refuse the vaccine; we further assume (with slight optimism) that only 40% of those who said they 'did not know', will refuse the vaccine. This yields an estimate of

$$8 + (80/100) \times 6 + (60/100) \times 9 + (40/100) \times 7 = 21\%$$

of UK adults refusing the vaccine. We assume, a little optimistically, that the proportion refusing the vaccine will be very similar, among UoB students (those on campus in TB1 of AY 2021/22), to among the general

population aged 16-75 (at the time of the survey), though this may be somewhat optimistic, as vaccine hesitancy is likely to be higher among the young than among the old (the latter being much more at risk from the consequences of COVID-19 infection). We also assume, again a little optimistically, that vaccine coverage among international students at the University of Bristol (those who will be on campus in TB1 of AY 2021/22), will be similar to that among home students. This yields an estimate that **79% of UoB students on campus in TB1 of the AY 2021/22, will have received a vaccine (both doses), in time for it to take effect by the start of TB1.**

Estimates on the impact of vaccination

Of course, no COVID-19 vaccine is 100% effective at preventing infection by COVID-19 (either symptomatic or asymptomatic infection), even among those who receive both doses. Vaccines typically work by both modifying the susceptibility of an individual to infection (if they are exposed to the virus), and modifying the chance that an infected individual will transmit infection to others (e.g., by reducing the viral load in a typical infected and vaccinated individual, compared to that in a typical infected and unvaccinated individual). Here, we follow the model of Gog et al [8], for the impact of vaccination. We denote by θ_S the factor by which vaccination reduces susceptibility to infection (either symptomatic or asymptomatic infection), and we denote by θ_T the factor by which vaccination reduces the rate of transmission from a uniform random infected but vaccinated individual, compared to that from a uniform random infected but unvaccinated individual. Intuitively speaking, the overall impact of vaccination on community transmission is given by the product $\theta_S\theta_T$.

There is currently quite a lot of uncertainty around the (current) values of θ_S and θ_T; new data relevant to their estimation is constantly emerging, and the true values will of course change as the strains in circulation change. Currently available data enables us to estimate θ_S somewhat more accurately than θ_T. The analysis of Voysey et al [16] of the Phase III trials of the Oxford-AstraZeneca vaccine yielded an estimate that two doses of the Oxford-AstraZeneca vaccine reduced the number of infections (both symptomatic and asymptomatic) by 59.9% (95% CI: 35.8%-75.0%), from two weeks after the administration of the second dose. This implies an estimate of $\theta_S = 0.401$ (95% CI: 0.250-0.642), for those strains in circulation during the Phrase III trials of the Oxford-AstraZeneca vaccine (which were essentially 'wild-type' SARS-CoV-2). The available data suggests that the Oxford-AstraZeneca vaccine has a similar impact (perhaps very slightly less) on the 'British' (or Kent) variant to on wild-type SARS-CoV-2; see e.g. [6]. Unfortunately, the study of Madhi et al [12] suggests that the Oxford/AstraZeneca vaccine is approximately one-sixth as effective at preventing mild/moderate illness caused by the South African variant, compared to that caused by wild-type SARS-CoV-2, so the value of θ_S (for the Oxford vaccine) is likely to become much closer to 1 (i.e., little effect), if the South African variant starts to circulate widely.

The data for the Pfizer vaccine (so far) is slightly better. A retrospective cohort study [15] of individuals in the US (Arizona, Minnesota and Wisconsin), vaccinated with the Pfizer vaccine, with screening conducted between 17th December 2020 and 8th February 2021, yielded an estimate that two doses of the Pfizer vaccine reduced the number of infections (both symptomatic and asymptomatic) by 80% (95% CI: 56%-91%); this implies an estimate of $\theta_S = 0.20$ (95% CI: 0.09–0.44), for those strains in circulation in Arizona, Minnesota and Wisconsin at the time. This study was conducted before the British variant became dominant in the US, but the large case-control study of Dagan et al [3] suggests that the Pfizer vaccine has similar effectiveness against the British variant, as against wild-type SARS-CoV-2. Some preliminary studies on the (e.g. the study of Kuzmina et al [11] of the neutralisation potency of post-vaccination sera) suggest that the Pfizer vaccine may be less effectiveness (and, possibly, much less effective) against the South African variant, than it is against wild-type SARS-CoV-2, though we await further data to be sure.

In view of the above, we consider five scenarios for the value of θ_S: 0.2, 0.4, 0.6, 0.8 and 1. We remark that the UK government has ordered 100 million doses of the Oxford/AstraZeneca vaccine, compared to only 40 million of the Pfizer vaccine, and that prior to 7th March, an estimated 11.9 million first doses of the Pfizer vaccine had been dispensed [10]. It is therefore likely that younger adults in the UK will the Oxford AstraZeneca vaccine more often than the Pfizer vaccine. (The Oxford vaccine is also produced in the UK, so

Table 1: Values of R in different scenarios for the values of θ_S and θ_T, with $v = 0.79$. Our 'default scenario' of $\theta_S = 0.4$ and $\theta_T = 0.6$, is indicated in bold.

θ_S \ θ_T	0.4	0.6	0.8	1
0.2	$0.27R_0$	$0.30R_0$	$0.34R_0$	$0.37R_0$
0.4	$0.34R_0$	$\mathbf{0.40R_0}$	$0.46R_0$	$0.53R_0$
0.6	$0.40R_0$	$0.49R_0$	$0.59R_0$	$0.68R_0$
0.8	$0.46R_0$	$0.59R_0$	$0.72R_0$	$0.84R_0$
1	$0.53R_0$	$0.68R_0$	$0.84R_0$	R_0

is less vulnerable to export restrictions). Hence, based on the above, we believe $\theta_S = 0.4$ may be closest to the truth, and we use this as our 'default' scenario, but it will be desirable to update these scenarios as more evidence emerges. We note that Gog et al [8] use the value $\theta_S = 0.6$ as a default, but they also consider the possible values $\theta_S = 0.4, 0.8$ and 1, in their sensitivity analysis.

There is more uncertainty around the value of θ_T. Following Gog et al [8], we consider four scenarios for its value: 0.4, 0.6, 0.8 and 1; we use $\theta_T = 0.6$ as our 'default' scenario. Behavioural considerations are important for θ_T: it is probable that vaccinated individuals will mix more freely with others, than vaccinated individuals, and this may negate the physiological impact of vaccination on the probability an infected individual will transmit to others (it is even possible that $\theta_T > 1$ due to such behavioural factors, but we do not consider this scenario here).

If R_0 is the basic reproduction number (of the strains in circulation at the time in question, in a completely unvaccinated population), then in a population where a proportion v of members are vaccinated, the effective reproduction number R is given by

$$R = (1 - v + \theta_S \theta_T v)R_0$$

(see Gog et al [8]). Our analysis predicts that, among University of Bristol students who will be on campus in TB1 of AY 2021/22, a proportion $v = 0.79$ will be vaccinated; combining this with our default-scenario assumptions that $\theta_S = 0.4$ and $\theta_T = 0.6$, yields

$$R = (1 - 0.79 + 0.4 \times 0.6 \times 0.79)R_0 = 0.40R_0.$$

Table 1 shows the values of R under the other scenarios for the values of θ_S and θ_T, listed above.

It is very important to emphasise that our 'default scenario' **assumes there is not widespread community transmission (in Bristol) of new variants that can escape the vaccines currently being distributed, during TB1 of AY 2021/22**. Preliminary research from South Africa [12] suggests that the Oxford/AstraZeneca vaccine is approximately one-sixth as effective at preventing mild/moderate illness caused by the South African variant, compared to that caused by wild-type SARS-CoV-2, so if community transmission of the South African variant (for example) were to become widespread in Bristol, the effect of the vaccination programme on the effective reproduction number would be very much smaller, and the situation would be closer to $\theta_S = \theta_T = 1$, i.e., the bottom right of Table 1. The UK government hopes to distribute 'boosters' to protect against new variants, distributing these to high-risk groups from September 2021 onwards [1], but such 'boosters' are not likely to be distributed to those of student age (excepting the highly clinically vulnerable), during Autumn 2021.

Estimates on the basic reproduction number of the SARS-CoV-2 strains likely to be circulating in TB1 of 2021/22

It is desirable to compare the effective reproduction number R which we predict for TB1 of the academic year 2021/22, with that seen in TB1 of the academic year 2020/21. Unfortunately, the SARS-CoV-2 strains

Table 2: Estimates of (reproduction number in TB1 of 2021/22)/(reproduction number in TB1 of 2020/2021), with vaccination coverage $v = 0.79$ in TB1 of 2021/22, in different scenarios for the values of θ_S and θ_T. Our 'default scenario' of $\theta_S = 0.4$ and $\theta_T = 0.6$, is indicated in bold.

θ_S \ θ_T	0.4	0.6	0.8	1
0.2	0.41	0.46	0.50	0.55
0.4	0.50	**0.60**	0.69	0.79
0.6	0.60	0.74	0.88	1.03
0.8	0.69	0.88	1.07	1.26
1	0.79	1.03	1.26	1.50

likely to be circulating in TB1 of 2021/2022 have a higher basic reproduction number (R_0) than those which were circulating in TB1 of 2020/2021, if only because the 'British' (or 'Kent') variant (which was not the dominant strain in Bristol during TB1 of 2020/21, but which has become dominant in the UK as a whole, and also in the South West of England, since then), has a basic reproduction number approximately 1.5 times higher than 'wild-type' SARS-CoV-2 [4]. We therefore estimate that, **provided new variants with even greater transmissibility than the Kent variant do not arise in the UK and become widespread**,

$$R_0[\text{TB1 of 2021/22}] = 1.5 \times R_0[\text{TB1 of 2020/21}]$$

Combining this with the default-scenario estimate of the previous section, which assumes **no widespread transmission of new variants that can escape the vaccines currently being distributed**, we obtain

$$\begin{aligned} R[\text{TB1 of 2021/22}] &= 0.40 R_0[\text{TB1 of 2021/22}] \\ &= 0.40 \times 1.5 \times R_0[\text{TB1 of 2020/21}] \\ &= 0.60 R_0[\text{TB1 of 2020/21}] \\ &\approx 0.60 R[\text{TB1 of 2020/21}]. \end{aligned}$$

Here, we neglect the effect of immunity due to prior infection among students in TB1 of 2020/21, and also the effect of immunity due to prior infection in the unvaccinated in TB1 of 2021/22, on the basis that these effects are very small. We therefore see that, under the above assumptions (**no very long delay of the vaccine rollout, 79% vaccine uptake among students, no widespread community transmission of new variants able to escape vaccines, and no widespread community transmission of variants more transmissible than the Kent variant**), the effective reproduction number in TB1 of 2021/22 may be approximately 40% lower than in TB1 of 2020/21, under the same level of stringency of non-pharmaceutical interventions (social distancing, etc).

Table 2 shows how the estimate of 0.60 (above) varies as we vary the values of θ_S and θ_T.

Estimates on differing levels of social distancing and other NPIs

The analysis of the previous section assumes the same level of stringency of non-pharmaceutical interventions (NPIs) in TB1 of 2021/2022 as in TB1 of 2020/21. (NPIs include social distancing, personal hygiene, cleaning and mask-wearing.) This, however, is obviously an unrealistic assumption, given that the UK government hopes to relax most, if not all, NPIs, during the summer (with 21st June being given as the earliest possible date for the removal of all restrictions on social contact). It is, of course, difficult or impossible to predict whether the UK government will hold to this plan, whether some social distancing rules will be reintroduced in the Autumn (in the event of a third wave in the summer, as is predicted under some unlocking scenarios by recent modelling of Whittles et al [17]), and whether voluntary social distancing (including among students)

will still be taking place. But we believe that, in view of the likely removal of many social distancing requirements, mask-wearing requirements, and other NPIs, that for our default scenario, instead of assuming a 40% reduction in the effective reproduction number (compared to TB1 of 2020/21), **the assumption of a 20%-40% reduction in the effective reproduction number (compared to in TB1 of 2020/21), would be more judicious**. As emphasised above, our default scenario assumes:

- no delay of longer than 26 days, to the UK vaccine rollout;
- no widespread community transmission (in Bristol), during TB1 of AY 2021/2022, of new variants that are able to escape the vaccines currently being distributed;
- no widespread community transmission (in Bristol), during TB1 of AY 2021/2022, of new variants with significantly greater transmissibility than the 'Kent' variant.

Appendix: Sensitivity analysis with respect to lower rates of vaccine refusal

The most recent ONS release of the Coronavirus and Vaccine Hesitancy Survey (Great Britain) [13], based on surveys taken between 13th January and 7th February (after the vaccine rollout had started), suggests that vaccine refusal rates among 16-29 year-olds may be lower than our 21% estimate above. Indeed, in that report it was estimated that, approximately 17% of UK residents aged 16-29 reported 'vaccine hesitancy', whereas 83% reported 'positive vaccine sentiment'. In this survey, those 'reporting positive vaccine sentiment' refers to those who reported:

- having received the vaccine, or
- having been offered the vaccine, and waiting to be vaccinated, or
- being very or fairly likely to have the vaccine, if offered;

those 'reporting vaccine hesitancy' refers to those who reported:

- having been offered the vaccine, but having declined the offer, or
- being very or fairly unlikely to have the vaccine if offered, or
- being neither likely nor unlikely to have the vaccine if offered, or
- don't know, or
- preferred not to say.

The last three categories within 'vaccine hesitancy' are fairly ambiguous, and we do not yet have a detailed breakdown of vaccine hesitancy between the five categories. We will assume, for our more optimistic scenario on vaccine refusal rates, that coverage among UoB students on campus in TB1 of AY 2021/2022, is 87%, rather than 79%. This yields the following predictions.

Table 3: Values of R in different scenarios for the values of θ_S and θ_T, with $v = 0.87$. Our 'default scenario' of $\theta_S = 0.4$ and $\theta_T = 0.6$, is indicated in bold.

θ_S \ θ_T	0.4	0.6	0.8	1
0.2	$0.20R_0$	$0.23R_0$	$0.27R_0$	$0.30R_0$
0.4	$0.27R_0$	$\mathbf{0.34R_0}$	$0.41R_0$	$0.48R_0$
0.6	$0.34R_0$	$0.44R_0$	$0.55R_0$	$0.65R_0$
0.8	$0.41R_0$	$0.55R_0$	$0.69R_0$	$0.83R_0$
1	$0.48R_0$	$0.65R_0$	$0.83R_0$	R_0

Table 4: Estimates of (reproduction number in TB1 of 2021/22)/(reproduction number in TB1 of 2020/2021), with vaccination coverage $v = 0.87$ in TB1 of 2021/22, in different scenarios for the values of θ_S and θ_T. Our 'default scenario' of $\theta_S = 0.4$ and $\theta_T = 0.6$, is indicated in bold.

θ_S \ θ_T	0.4	0.6	0.8	1
0.2	0.30	0.35	0.40	0.46
0.4	0.40	**0.51**	0.61	0.72
0.6	0.51	0.66	0.82	0.98
0.8	0.61	0.82	1.03	1.24
1	0.72	0.98	1.24	1.50

We see that, in our 'default scenario' for vaccine effectiveness ($\theta_S = 0.4$, $\theta_T = 0.6$), and under the above assumptions (**no very long delay of the vaccine rollout, no widespread community transmission of new variants able to escape vaccines, and no widespread community transmission of variants more transmissible than the Kent variant**), and assuming the more optimistic vaccine coverage rate of 87% among students, the effective reproduction number in TB1 of 2021/22 may be approximately 49% lower than in TB1 of 2020/21, under the same level of stringency of non-pharmaceutical interventions (social distancing, etc). As outlined above, the non-pharmaceutical interventions in place are likely to be much less stringent, so we believe that (in this higher-vaccination-coverage scenario), **the assumption of a 25%-49% reduction in the effective reproduction number (compared to in TB1 of 2020/21), would be more judicious.**

It is not yet clear whether the negative publicity due to the (albeit temporary) suspensions of the Oxford-AstraZeneca vaccine, by several EU countries in mid-March (due, mainly, to seven cases of sinus venous thrombosis among a cohort of approximately 3.5 million vaccinated German women), will affect rates of vaccine refusal in the UK population; we await further releases of the ONS Coronavirus and Vaccine Hesitancy survey, for more clarity on this.

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