Effectiveness of testing for COVID-19: evidence from airline trials at Heathrow Airport

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Executive summary

Testing (and quarantine) has become a key part of international travel. Despite a significant vaccination programme in the UK and globally, and a reduction in COVID-19 deaths worldwide, the ability to screen international passengers and place controls on travel remains important in order to limit the spread of the virus. Testing is therefore likely to be used for international travel for at least some countries for the foreseeable future.

Current testing requirements for international air travel vary by country in terms of the type of test required, when testing is required, and how many tests are required. Testing requirements have also changed over time, often with little notice provided to passengers and the aviation sector in general, disrupting travel and creating confusion.

Part of the reason for the differences in testing requirements across countries, and the changes, is uncertainty around the role of pre-symptomatic and asymptomatic transmission of COVID-19, and the sensitivity of different types of tests. This has led to the introduction of complex testing regimes, often requiring multiple tests at different time points. In the UK, the testing regime currently costs arriving passengers £210, in addition to a pre-departure test to enter the UK and any testing required as part of the outbound trip. If passengers arrive from a 'red list' country, they are required to quarantine at a hotel at a cost of £1,750 for ten days.

As international travel gets set to resume, the ability to reopen borders safely, and to do so at scale, will be limited by the capacity for testing and the effect of testing on passenger volumes (e.g. due to the cost). It is therefore important to develop and understand the empirical evidence base on the effectiveness of air passenger testing.

In late 2020, COVID-19 testing for international passengers started taking place at Heathrow Airport and on a trial basis for several airlines operating at Heathrow. The trials run by Virgin Atlantic, American Airlines / British Airways / **one**world, and United Airlines were set up on routes between the Caribbean and the USA to the UK to generate an evidence base for future policy. Additionally, Collinson and Cignpost started providing testing facilities at Heathrow to meet the pre-departure testing requirements for passengers leaving the UK. In total, data from around 71,000 COVID-19 tests has been collected over the last six months. This report analyses this real-world data to provide insights into the effectiveness of different testing regimes.

The key findings from the analysis of the data are as follows.

- There is some evidence that passengers actively choose flights where there is COVID-19 testing compared to those without such testing.
- Approximately three quarters of cases of COVID-19 can be identified with pre-departure, on-departure, or on-arrival testing. This finding is substantially higher than previous estimates of the effectiveness of pre-departure testing, but is consistent with findings from a study at Toronto Pearson Airport.
- Infection levels detected by some PCR tests[1] at Heathrow Airport appear to be in line with the level expected from rates in the community.

[1] Conducted by Cignpost.

- LAMP testing and antigen testing show similar effectiveness, although they identify fewer positive cases than would be expected when comparing them to community prevalence rates. The lower effectiveness may be explained by unobserved selection factors (e.g. deprivation level or risk-averse behaviour of passengers), different population samples, as well as test sensitivity.
- While antigen testing appears to identify fewer cases than LAMP testing, our report on rapid testing[2] shows that the specific antigen test used (e.g. the brand of test) can have a significant impact on the antigen test sensitivity.
- As part of our study, we conducted interviews with Heathrow Airport and the airlines that participated in the trials to understand the operational factors associated with implementing different testing schemes that affect passengers and providers. We have identified two main factors that are likely to affect operations in the aviation sector if testing remains in place as demand for air travel returns: lack of consistent local and international standards; and suitability of the existing infrastructure.
- Testing schemes create monetary and non-monetary (e.g. time) costs for passengers and affect the operations of airlines and airports. However, ensuring that there is sufficient and easily accessible capacity for testing, at the lowest cost possible, would allow the aviation sector to restart at scale and therefore help with recovery.

The outputs from this work are intended to inform the UK's Global Travel Taskforce, which was re-established in early 2021, but the results are relevant for all countries using testing.

[2] IATA (2020), 'Assessment of the effectiveness of rapid testing for SARS-Cov-2', 25 March.

1 Introduction

A year into the pandemic, testing is being used more than ever to reduce potential COVID-19 risks from international travel. Even as vaccines are rolled out, there is likely to be a continued role for testing for some time to reduce the risk of potential infections, especially those from variants of concern, being imported. In this context, it is critical to understand the efficacy of testing schemes and how to operationalise them. Appropriate and proportional testing measures could help the aviation sector recover while protecting public health.

This report follows previous modelling conducted by Oxera and Edge Health on the efficacy of testing and quarantine schemes in reducing the likelihood of people with COVID-19 entering the UK and spreading the virus to others.[3] This study complements our previous modelling by using real-world data and evidence to evaluate the effectiveness of testing and quarantine schemes. The focus of this report is two-fold:

- to use real-world data to assess the efficacy of testing and quarantine schemes;
- to use recent experience of implementing testing of international air passengers to assess the operational challenges associated with testing and quarantine schemes.

For this study, Heathrow Airport, **one**world, British Airways (BA), American Airlines (AA), United Airlines, and Virgin Atlantic partnered to provide evidence on air passenger testing schemes.

Data was collected from three trials conducted by:

- AA/BA/**one**world on routes from the USA to Heathrow;
- United Airlines on the route from Newark Airport to Heathrow;
- Virgin Atlantic on the route from Heathrow to Barbados.

Data was also collected from Collinson and Cignpost, which have been conducting pre-departure testing at Heathrow. Overall, data has been collected from 71,000 COVID-19 tests.

We have used this data to assess the effectiveness of testing schemes based on the point in time at which the test was administered and the type of test that was administered. We have also evaluated the operational challenges and potential solutions to implementing these testing schemes at scale, based on interviews with airlines and Heathrow.

This work adds to existing real-world evidence on air passenger testing, notably the 'Rome trials' for Delta flights between the USA and Rome, studies on post-arrival tests conducted at Toronto Pearson Airport,[4] and our previous work assessing real-world evidence on testing scheme efficacy.[5]

[3] Oxera and Edge Health (2020), 'Modelling the effectiveness of airport testing regimes', 6 November; Oxera and Edge Health (2021), 'Effectiveness of dual-testing schemes for air passengers', 18 March; Oxera and Edge Health (2021), 'Assessment of the effectiveness of rapid testing for SARS-CoV-2', 25 March.
[4] Goel et al. (2021), 'COVID-19 International Border Surveillance Cohort Study at Toronto's Pearson Airport', Table 3, https://www.medrxiv.org/content/10.1101/2021.02.25.21252404v1?fbclid=IwAR2w6AFhERZM4EBNc5LhkoIzni34N8SseuOAajg6xdUguCTPhBDFtyxqkVQ
[5] Oxera and Edge Health (2020), 'Review of case studies of effectiveness of testing regimes', November.

The rest of the report is structured as follows:

- section 2 sets out our methodology for this study;
- section 3 presents the results of our analysis of testing efficacy;
- section 4 presents the results of our analysis on the operational challenges associated with implementing testing and quarantine schemes;
- section 5 concludes.

The appendices provide further detail on our analysis of passenger demographics and sensitivity analyses.

2 Methodology

2.1 Summary of trial designs

For this study, we have used data from three different airline trials and from pre-departure tests conducted at Heathrow. Each airline trial was set up on different routes, with different test timings (e.g. pre-departure, post-arrival), and using different types of tests. The trials are summarised in Table 2.1 below.

In the AA/BA/**one**world trial, participants were tested at multiple points in time, making it possible to assess whether there are cases of COVID-19 that are not initially detectable, but that become detectable with a test at a later stage (e.g. on departure/arrival, post-arrival).[6] This trial was similar to a study conducted at Toronto Pearson Airport, where passengers were tested at multiple points in time (see section 3.2.1 for a summary of the Toronto Pearson trial results). Passengers on trial flights from airports across the USA to Heathrow could choose to enrol in the trial,[7] phase I of which ran between 25 November and 18 December 2020.[8]

In the United Airlines trial, participants were tested at one point in time (on departure). Flights from Newark to London were split into 'tested' and 'non-tested' flights, such that all passengers on tested flights had to take an on-departure test.[9] Passengers who did not want to take part in the trial could fly on the non-tested flights on the same route, which were on different days. Passengers could switch from tested flights to non-tested flights and vice versa ahead of their scheduled departure. The trial took place between 16 November and 11 December 2020.

The Virgin Atlantic trial operated on one flight from Heathrow to Barbados on 10 December 2020, for which all passengers were required to be tested at multiple points in time.

[6] For example, once passengers have passed their incubation period.
[7] Routes included DFW–LHR (AA); JFK–LHR (BA); LAX–LHR (BA); MIA–LHR (BA).
[8] For this study, we have used data from phase I of this trial. Phase II—where tests are administered D-72, on arrival, and five days post-arrival—is ongoing.
[9] The United Airlines trial operated along the Newark–Heathrow route for flights on Mondays, Wednesdays, and Fridays for the flight designator UA14.

Table 2.1 Airline testing trial design

Trial	Test location	Test timing	Test type	Test provider
AA/BA/**one**world (phase I)	USA: DFW, JFK, LAX, MIA	72 hours pre-departure (D-72)	RT-PCR	Let's Get Checked
	London Heathrow	On arrival	RT-LAMP	Collinson
	UK—mail-in test	Three days post-arrival	RT-PCR	Collinson
Virgin Atlantic	UK—at home testing	72 hours pre-departure (D-72)	RT-PCR	Multiple[10]
	London Heathrow	On departure	Antigen	Collinson
	Barbados	Five days post-arrival	RT-PCR	Multiple[11]
United Airlines	Newark Airport	On departure	NAAT (Abbott ID Now)	Premise Health

Source: Oxera and Edge Health.

In addition to trial data, we have used pre-departure tests conducted by Collinson and Cignpost for passengers at Heathrow in our analysis. This testing was initially set up last year to fulfil pre-departure testing requirements for certain countries. Since then, many more countries have started to require pre-departure testing. Antigen testing, RT-LAMP testing, and RT-PCR testing are all available at Heathrow.[12]

Each trial's design determined which aspects of the testing schemes we could evaluate and how we could evaluate them. The analytic approaches we have used are discussed below.

2.2 Analytical approaches used to evaluate testing scheme efficacy

In our analysis, we evaluated two aspects of testing schemes: test timing and test type. For the trials that involved repeated testing (i.e. AA/BA/**one**world and Virgin Atlantic), we evaluated efficacy by benchmarking the number of COVID-19 cases identified by a test at a certain point in time to the identified cases at other test administration times. For trials with a single test (i.e. United Airlines and Collinson), we benchmarked the number of COVID-19 cases identified to estimated community prevalence to determine the effectiveness of the test type in identifying COVID-19 cases.

Table 2.2 below summarises the data sources and analytical approaches we have used to evaluate the efficacy of different test timings and test types.

[10] Results data from the first test conducted in the trial was unavailable.
[11] Results data from the last test conducted in the trial was unavailable.
[12] While test timing relative to the flight is not collected in this data, it is assumed that RT-PCR tests are taken a maximum of 72 hours pre-departure and that LAMP/antigen tests are more likely to be taken on departure (because of their short turnaround times).

Table 2.2 Evaluation approach for testing efficacy

Aspect of testing scheme	Data used	Study measure	Analytical approach	Sample size
Test timing	AA/BA/**one**world (phase I)	Positive cases identified at each test administration time	Calculate the percentage of positive cases identified at each test administration time	400 tests administered
	Virgin Atlantic	Positive cases identified at each test administration time	Calculate the percentage of positive cases identified at each test administration time[13]	161 tests administered
Test type	United Airlines	Positive cases identified via nucleic acid amplification testing rapid testing technology	Compare the prevalence of trial tests to estimated community prevalence[14]	700 tests administered
	Collinson	Positive cases identified via LAMP/antigen technology	Compare the prevalence of pre-departure tests to estimated community prevalence[15]	70,000 tests administered[16]

Source: Oxera and Edge Health.

We also assessed demographic and behavioural factors that might influence infection prevalence in the trial population. We compared the demographics and behaviour of trial participants to:

- the demographics/behaviour of all air passengers on the same route;
- the demographics/behaviour of the (origin) community.

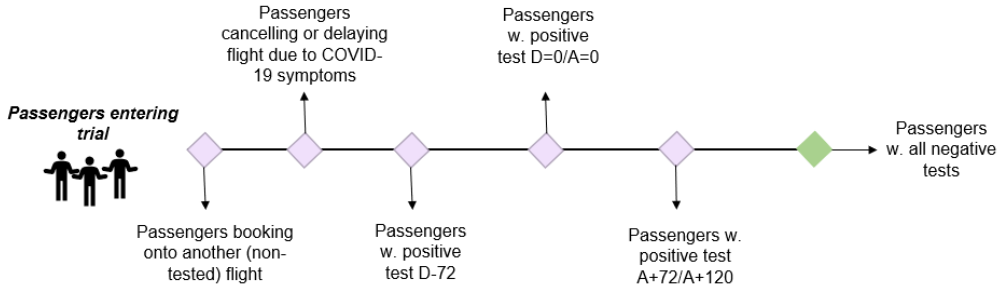
Comparing the demographics of the trial population to those of the general air passenger population helped us to determine whether the infection prevalence observed in trial participants was representative of all air passengers on the same route. We also evaluated rebooking data to assess whether passengers were opting into or out of tested flights (see section 3.1.2). If passengers were opting into tested flights because they felt safer on flights with pre-departure testing, this could indicate that they are more risk-averse. Risk aversion is also correlated with factors such as social distancing and mask wearing, which could reduce prevalence among trial participants relative to other air passengers. Rebooking could also occur for other reasons, such as tested flights being at more convenient times or being less likely to be cancelled.

We also compared trial participant demographics to community demographics. This allowed us to assess (and control for, where possible) potential reasons for differences in community and air passenger prevalence (see section 3.1.1). In addition to demographics, air passenger prevalence may differ from that of

[13] As test results from D-72 and day five were not available, we were not able to assess this quantitatively.
[14] We assumed that the prevalence was equal to that of the departure destination (New York City). As public health surveillance data is not available on community prevalence for this region, we used infection fatality ratios available from the Centers for Disease Control and Prevention (CDC) to extrapolate community caseload from deaths (see section 3.2.1 for more details). The data was weighted by age differences between air passengers and the community.
[15] We used data available from the ONS Infection Survey for England to benchmark pre-departure testing data. The data was weighted by age and test administration time.
[16] Of these, we used 37,000, as we restricted our sample to tests taken before 15 January 2021, when the Netherlands put in antigen testing requirements after another pre-departure PCR test. We would expect this dual-testing scheme to reduce the prevalence in the antigen test sample after 15 January 2021.

the community if passengers decide not to fly because they develop symptoms consistent with COVID-19 (see Figure 2.1 below). If passengers decide not to fly due to symptoms consistent with COVID-19, we would expect this to reduce the prevalence in air passengers relative to that of the community. We used rebooking data to assess whether passengers might be opting out of flying due to COVID-19-related symptoms (see section 3.1.2).

Figure 2.1 Stages at which infected passengers could opt out of the trial or be detected



Source: Oxera and Edge Health.

2.3 Operational challenges when implementing testing

In addition to the quantitative assessment of the efficacy of each of these trials presented in this report, we provide a qualitative assessment of the operational challenges associated with implementing testing schemes. To gather evidence for this assessment, we conducted interviews with individuals involved in implementing the trials from each airline as well as from Heathrow. The interview questions asked during these sessions are included in Appendix A1. A summary of the results from these interviews is presented in section 4.

3 Testing efficacy

In this section, we present our analysis of the data on demographics and rebooking to assess potential reasons for differences in the infection prevalence in the trial population compared to the general air passenger population and the community (section 3.1). We then present our analysis of the data on test positivity to assess the efficacy of different test timings and test types (section 3.2).

3.1 Determinants of SARS-Cov-2 infection prevalence in trial participants

3.1.1 Demographics

Certain demographic factors are associated with higher or lower prevalence levels. To assess how this might affect trial participants, we compared the demographics (i.e. age band and gender) of the trial population to two groups:

- all air passengers on the same route;
- the (origin) community.

We did not find material differences between the trial population and all air passengers on the same route during the month of the trial or historically[17] (see Appendix A2 for detailed analysis). This suggests that there are no observable factors to indicate that SARS-Cov-2 infection prevalence should differ in the trial population compared to the overall air passenger population. However, we note that there could be differences in unobserved factors, such as income level or journey purpose, that could in turn have an impact on differences in prevalence rates.

We also compared prevalence among air passengers to origin community prevalence. We compared prevalence among air passengers on the United Airlines trial to estimated prevalence in New York City, and we compared the Collinson pre-departure data to community prevalence in England. Across both datasets, we found that a smaller proportion of air passengers were children or elderly compared to the community (see Appendix A3 for detailed analysis). As the elderly tend to have fewer in-person contacts, their prevalence is lower than other groups.[18] This suggests that air passenger prevalence may be higher than that of the general population. For this reason, we controlled for age distribution when benchmarking air passenger prevalence to that of the community (see section 3.2.2).

On the other hand, unobserved factors, such as income level, could suggest that air passenger prevalence may be lower than that of the general population. For example, Public Health England has noted that there is lower prevalence in lower deprivation groups.[19] As higher deprivation groups are less likely to fly, this would reduce air passenger prevalence relative to that of the origin community.

[17] Some demographic characteristics of trial participants were statistically different from the characteristics of the travelling population at the time of the trial. However, the scale of the differences was not material.
[18] Based on UK data – ONS Infection Survey.
[19] Based on UK data – ONS Infection Survey.

3.1.2 Passenger behaviour

There are several types of behaviour that can influence SARS-Cov-2 infection prevalence. As with demographics, we compared the behaviour of trial participants to that of other air passengers and to the community.

First, once a passenger decides to fly, passengers who are more risk-averse may prefer travelling on flights with pre-departure testing rather than flights without testing. Risk aversion is also correlated with behaviours such as social distancing and mask wearing, which reduce the risk of becoming infected prior to flying. If risk-averse individuals mainly book onto tested flights, it could result in lower prevalence rates among trial participants than the overall air passenger population. Second, if passengers with symptoms consistent with COVID-19 choose not to fly, air passenger prevalence will be lower than that of the community.

We used data on passenger rebooking to investigate:

- passengers amending their bookings so that they switch from being on a non-tested flight to a tested flight or vice versa (which may be indicative of passenger risk preferences). These rebooking patterns may also be indicative of factors such as flights participating in the trial being less likely to be cancelled;
- passengers rebooking their flights in the days just prior to flying (which may be indicative of passengers choosing not to fly due to symptoms consistent with COVID-19). Rebooking in the days just prior to flying could also be consistent with more general changes to rebooking patterns since the beginning of the pandemic. For example, passengers now face increasingly uncertain government travel restrictions so they may cancel their bookings close to the time of departure as a result.

We evaluated rebooking patterns for the AA/BA/**one**world trial by looking at passenger rebooking data between tested and non-tested flights.[20] While testing was not mandatory on AA/BA/**one**world trial flights, passengers wanting to participate in the trial could still have opted into these flights by rebooking.

For the subpopulation of passengers who rebooked (but did not cancel) their flights, we observed whether they moved from a trial flight to a non-trial flight or vice versa.[21] Table 3.1 below evaluates this for all passengers where the:

- date of initial booking was before the trial announcement, i.e. the passengers booked their flights before they were aware of the trial;
- date of rebooking was after the trial announcement, i.e. the passengers might have been aware of the trial when they rebooked;
- initial flight booked was during the trial;
- rebooking type was changing the flight date;[22]

[20] Sufficiently disaggregated data from United Airlines was not available for this analysis and Virgin Atlantic only had one trial flight, so it was not possible to observe rebooking from one trial flight to another.
[21] While the AA/BA/oneworld trial did not require mandatory testing for all passengers on flights, it is still possible that passengers opted into flights where testing was an option either because they wanted to participate in the trial or wanted to be on a flight where at least some of the other passengers were tested.
[22] Cancellations were excluded, as the cancellation reason is unknown. Likewise, rebooking in cases where the destination changed were excluded, as trials were on specific routes so it is less likely that flights were rebooked because air passengers did not want to be on a tested flight.

- date was changed to a date within the trial period, as changing the date of the flight by, for example, one year would be an unlikely response to the trial compared to a passenger who moves their flight by a day.[23]

Using the above criteria, we observe that self-selection from being in the trial to opting out of the trial was relatively low, at 13%, whereas self-selection into the trial was more common, at 40% (see Table 3.1). This may illustrate the value that passengers assign to being on a tested flight where they, or at least some of the passengers, are tested.

Table 3.1 Self-selection into trial: AA/BA/oneworld

	…to out of trial	**…to in trial**	**Total**
From out of trial…	171 (**60%**)	113 (**40%**)	284
From in trial…	53 (**13%**)	356 (**87%**)	409
Total	224	469	693

Note: 'From out of trial…to out of trial' represents passengers whose initial bookings were on a non-trial flight and whose rebookings were on a non-trial flight. 'From in trial…to in trial' represents passengers whose initial bookings were on a trial flight and whose rebookings were on another trial flight. The other conditions represent movements from non-trial flights to trial flights or vice versa. Percentages represent row-wise proportions, for example 40% of passengers who changed their flight date from a non-trial flight rebooked on a trial flight.

Source: Oxera and Edge Health.

We also assessed whether passengers rebooked their flights in the days just prior to flying, which might be indicative of passengers choosing not to fly due to symptoms consistent with COVID-19. This helped us to assess whether passenger behaviour (i.e. rebooking a flight pre-departure if they develop symptoms) might lead to air passenger prevalence being lower than that of the community.

Absent information on reasons for rebooking, it is not possible to identify the scale of rebooking that is related to a person having (symptoms consistent with) COVID-19. To analyse rebooking that might be associated with symptomatic passengers,[24] we have analysed rebookings around the flight date.[25] We define rebooking that is more likely to be related to COVID as:

- rebooking up to two days before the flight date;
- rebooking to at least 14 days after the flight date or cancellations.[26]

We consider rebookings that meet these two criteria to be relevant because passengers are likely to decide not to fly due to symptoms close to the time of

[23] These selection criteria have been applied to ensure that the initial flight was not affected by the trial announcement but the rebooking might have been. The initial flight date and rebooked flight date have been restricted to trial period to ensure relevance. The removal of cancellations may result in underestimating the selection out of the trial if passengers cancelled their bookings as a response to the trial announcement. However, as free rebooking was offered to passengers who did not want to participate in the Virgin trial, whereas cancellation was costly, and passengers were able to choose not to participate in the AA/BA/oneworld trial, this may not be a material concern. See Virgin Atlantic (2020), 'Virgin Atlantic launches pre-departure Covid-19 testing trial on Heathrow-Barbados flights', 27 November, https://corporate.virginatlantic.com/gb/en/media/press-releases/pre-departure-covid-19-testing-trial-on-heathrow-barbados-flight.html

[24] Or passengers who tested positive for COVID-19. This was not mandatory for the majority of flights at the time of the trial, but the small number of people who participated in the trial and tested positive pre-departure might also have been captured here.

[25] D-72 is a common type of pre-departure testing scheme. If such a testing scheme were in place, test results would be obtained on average on D-48. A COVID test was not mandatory for flights covered in our sample. Therefore, rebooking behaviour that is COVID-relevant might have involved a passenger getting sick before the flight, getting a positive result from a test to check if they had COVID even though it was not mandatory, or showing symptoms.

[26] Rebookings with this definition represented 7.3% of all rebookings in 2020.

departure and passengers would need to rebook at least 14 days after the original flight date in order to recover fully from COVID-19.

There was a moderate increase in rebooking to at least 14 days after the flight date (+1.2%) in 2020 relative to 2019 (see Table 3.2), some of which might have been related to COVID-19 symptoms. There was also a significant increase in cancellations (+21.3%), some of which might also have been related to COVID-19 symptoms.

Other than rebooking due to symptoms consistent with COVID-19, there are many reasons that a passenger's rebooking would satisfy these two criteria. For example, the increased uncertainty regarding government travel restrictions might lead passengers to rebook to another date in the future. Rebooking could also be in response to changing airline rebooking policies. We therefore considered the difference in the shares of rebooking that satisfied the two criteria above in 2019 compared to 2020 in order to provide an upper bound to rebooking behaviour consistent with COVID-19, as defined by our criteria above.[27]

Table 3.2 Rebooking consistent with COVID-19-related reasons

Rebooking	Rebooking Type	2019	2020	Annual change
Within 14 days	Change date	56.7%	37.9%	-18.8%
	Change route	14.3%	12.0%	-2.3%
	Sub total	**71%**	**49.9%**	**-21.1%**
More than 14 days (potentially COVID related)	Change date	1.0%	2.2%	+1.2%
	Change route	5.0%	3.6%	-1.4%
No rebooking	Cancellation	23.0%	44.3%	+21.3%
	Sub total	**29%**	**50.1%**	**+21.1%**

Source: Oxera and Edge Health.

3.2 Efficacy of testing regimes

3.2.1 Test timing

In the Virgin Atlantic trial, a PCR test was required 72 hours before departure, an antigen test was required on departure, and a further PCR test was required five days post-arrival. The results data for the PCR tests 72 hours pre-departure was not available to us, but no passengers tested positive with the antigen test on departure.[28] While the sample size for this trial was too small for the results to be statistically significant, this suggests that additional on-departure testing may not be necessary in the presence of pre-departure testing.[29]

[27] This would provide an upper bound to the share of increase in rebooking for COVID-related reasons as there might be other reasons for the difference in shares that are not possible to identify due to data restrictions.
[28] We also note that the results of the post-arrival test were not available.
[29] Although theoretical modelling suggests that this dual-testing set-up can screen up to 10% more infectious days. See Oxera and Edge Health (2021), 'Effectiveness of dual-testing schemes for air passengers', 18 March.

In the AA/BA/**one**world trial, PCR testing was required 72 hours pre-departure, LAMP testing was required on arrival, and PCR testing was required three days post-arrival. The results of the trial are presented in Table 3.3 below.

Table 3.3 AA/BA/oneworld trial results

Test timing	Test type	Positive cases	Tests	Positivity rate	Lower CI	Upper CI
Pre-departure	RT-PCR	5	400	1.25%	0.54%	2.89%
On-arrival	RT-LAMP	0	278	0.00%	0.00%	1.36%
Three days post-arrival	RT-PCR	1	222	0.45%	0.08%	2.51%

Source: Oxera and Edge Health based on AA/BA/oneworld.

Of the six positive cases identified in the study, five were identified pre-departure and one person was identified three days post-arrival. Given the possibility that an infection might have been acquired following the pre-departure PCR test, and considering that compliance with post-arrival quarantine requirements may vary across individuals, it is difficult to definitively determine the point at which the individual was infected. Cases detected three days post-arrival could therefore be from: i) cases acquired before the pre-departure PCR test that were not initially detected; ii) cases acquired after the pre-departure test; or iii) cases acquired post-arrival (though many infections are not detectable three days post exposure). Both i) and ii) reflect potentially imported infections, while iii) is simply reflective of domestic COVID-19 risk.

Approximately 27% of trial participants (i.e. those who took the pre-departure tests) did not take the on-arrival test, and approximately 42% of trial participants did not take the post-arrival test after three days.[30] To control for this, we assumed that the positivity rate for those who did not take the subsequent tests was the same as for those who continued to participate in the trial, before calculating the percentage of positive cases detected at each phase. Accounting for this means that 74% of cases were identified pre-departure and 26% of cases were identified three days post-arrival.[31]

While the sample size of this study is too small to show a statistically significant difference in case positivity across test administration times, the results are consistent with a larger trial conducted at Toronto Pearson Airport, as set out in Table 3.4.[32] We also note that AA/BA/**one**world is currently undertaking phase II of its trial, which will lead to larger sample sizes.

Table 3.4 Toronto Pearson trial results

Time	Test type	Cases	Tests	Positivity rate	Lower CI	Upper CI
Arrival	RT-PCR	167	16,361	1.02%	0.87%	1.19%
Day 7	RT-PCR	67	13,197	0.51%	0.39%	0.64%
Day 14	RT-PCR	14	11,610	0.12%	0.07%	0.20%

Source: Goel et al. (2021), 'COVID-19 International Border Surveillance Cohort Study at Toronto's Pearson Airport', Table 3,

[30] Once the 11 inconclusive test results from the pre-departure testing are excluded from the initial sample of 400 tests, we assume that individuals with inconclusive tests would not be permitted to fly.
[31] Accounting for passengers not taking the subsequent tests, 5 cases would still be identified pre-departure, but 1.72 (rather than 1) cases would be identified on day three.
[32] See Goel et al. (2021), 'COVID-19 International Border Surveillance Cohort Study at Toronto's Pearson Airport', https://www.medrxiv.org/content/10.1101/2021.02.25.21252404v1?fbclid=IwAR2w6AFhERZM4EBNc5LhkoIzni34N8SseuOAajg6xdUguCTPhBDFtyxqkVQ

https://www.medrxiv.org/content/10.1101/2021.02.25.21252404v1?fbclid=IwAR2w6AFhERZM4EBNc5LhkoIzni34N8SseuOAajg6xdUguCTPhBDFtyxqkVQ

In the Toronto Pearson study, 67% of infections were detected on arrival, 27% of infections were detected seven days post-arrival, and 6% of infections were detected 14 days post-arrival. This suggests that most cases can be captured with pre-departure/on-departure/on-arrival testing, with a smaller marginal benefit for additional post-arrival quarantine and testing requirements.

These results are also consistent with the theoretical modelling we have undertaken, which shows that a high proportion of infections can be captured via pre-departure or on-departure testing, without the need for additional testing and quarantine requirements.[33]

3.2.2 Test type

In this section, we present our assessment of the efficacy of a variety of types of tests, including:

- nucleic acid amplification testing (NAAT) (specifically the Abbott ID Now), using data from the United Airlines trial;
- LAMP tests, using Collinson pre-departure data;
- antigen tests, using Collinson pre-departure data.

For the NAAT test used in the United Airlines trial, we estimate efficacy relative to estimated prevalence in the community of flight origin (New York City). For the LAMP and antigen tests used for Collinson pre-departure testing, we estimate efficacy relative to PCR test positivity in the community of flight origin (England). We also contextualise these results based on reported Collinson and Cignpost PCR positivity.

In the United Airlines trial, test positivity for on-departure NAAT testing was 0.43%.[34] We benchmark this to estimated community prevalence[35] in New York City, as the majority (90%) of trial passengers' flights originated from Newark Airport (the remaining 10% of passengers had connecting flights). We model prevalence in the New York City community using the methodology from Bohk-Ewald et al. (April 2020).[36] We present central, low, and high estimates of community prevalence based on central, low, and high input parameters from the CDC.[37] This results in an estimated average community prevalence of 1.2% (lower bound prevalence: 0.67%, upper bound prevalence: 2.48%). The

[33] Oxera and Edge Health (2021), 'Effectiveness of dual-testing schemes for air passengers', 18 March.
[34] Based on the Abbott ID Now NAAT test being administered to air passengers. The 95% confidence interval is 15–1.25%.
[35] Community prevalence surveillance data (such as that in the ONS Infection Survey in the UK) is not available for the USA or New York area. Therefore, we benchmarked the trial's reported prevalence to estimated community prevalence. We did not benchmark to reported cases as reported cases tend to underestimate population positivity rate/prevalence—at the beginning of the pandemic, this was mainly due to testing capacity. Testing capacity has improved but not everyone who is infected takes a test.
[36] First, we scaled reported deaths to actual cases using Infection Fatality Ratios (IFR) from the CDC. We used three different sets of IFR values based on the central, high, and low IFR values set out by the CDC. See Centers for Disease Control and Prevention (2021), 'Box 1 Description of the Five COVID-19 Pandemic Planning Scenarios', https://www.cdc.gov/coronavirus/2019-ncov/hcp/planning-scenarios.html#box1. We adjusted the IFRs to account for the age distribution of air passengers. There tended to be fewer children and elderly air passengers compared to the overall population. We assumed that the propensity to become infected is proportional to the air passenger age pyramid, and then assumed that individuals remain infected for a period of ten days.
[37] We used three different sets of IFR values based on the central, high, and low IFR values set out by the CDC. See Centers for Disease Control and Prevention (2021), 'Box 1 Description of the Five COVID-19 Pandemic Planning Scenarios', https://www.cdc.gov/coronavirus/2019-ncov/hcp/planning-scenarios.html#box1

relatively large range of estimated prevalence reflects the uncertainty in this estimation method.

While the central community prevalence estimate of 1.2% is higher than the 0.43% prevalence in the United Airlines trial, it is still within the confidence intervals of the trial. This suggests that the NAAT rapid testing used in the United Airlines trial may be an effective way of detecting cases. Furthermore, as some infected individuals may choose not to fly due to symptoms, prevalence in the air passenger population may be lower than that of the general population.

The data provided by Collinson includes pre-departure tests administered via PCR, LAMP, and antigen testing. Cignpost data includes only PCR tests. As the PCR, LAMP, and antigen tests were all administered to different populations, there are several factors that could affect reported prevalence. These include the following.

- Differences in the relative number of tests taken in different time periods (for example, more or fewer PCR/LAMP/antigen tests being administered in different time windows).
- Differences in test timings (i.e. PCR is generally administered three days pre-departure and LAMP/antigen testing is generally administered on departure), leading to potential differences regarding passengers' origins in the UK (and therefore their COVID-19 risk level). For example, people who are administered PCR tests three days pre-departure are more likely to be staying in the London area (which historically has had higher COVID-19 prevalence) than individuals taking LAMP/antigen tests on departure (who could be travelling to the airport from various other locations within the UK).
- Different populations using the testing facilities. For example, community members may be more likely to use PCR testing than LAMP/antigen testing. As LAMP/antigen tests are administered on departure, they are more likely to be used by air passengers. If community members are more likely to get tested when they have symptoms or suspect that they have COVID-19, this would lead to higher positivity rates from PCR tests relative to the other testing types.

To assess these selection factors, we benchmarked the Collinson PCR data to that of the community and to the Cignpost data.

The Collinson data available for RT-PCR testing suggests that there was a PCR positivity rate of 3.7%[38] between 1 December 2020 and 26 February 2021. This is higher than that observed in the England and London communities over the same time period for the same age groups.[39,40] Test positivity was 1.9% in England,[41] and 2.7% in London.[42] The Collinson data is above the confidence intervals for London prevalence during that time.

In the Cignpost PCR data, it is indicated whether a test was administered to someone from the community or to an air passenger. Using this differentiation, we found that air passenger prevalence between December 2020 and

[38] 95% confidence interval of 3.3–4%.
[39] We were able to account for duplicated positive results across multiple PCR tests, but did not have access to potential duplicates across test types, should they occur (for example, if a PCR test is used for confirmatory testing should someone test positive via another test type).
[40] Community estimates were weighted by the air passenger age distribution (which tended to be more middle-aged, as outlined in section 3.1.1) and by the time at which the test was administered.
[41] 95% confidence interval 1.65–2.06%
[42] 95% confidence interval 2.22–3.16%.

February 2021 was 1.46%.[43] For the community, we found that prevalence was 2.58% (very similar to the estimated London community prevalence of 2.7%).[44] This suggests that air passengers tend to have lower prevalence rates than the general community.

Taken together, this suggests that community members are likely to be using Collinson's PCR testing facilities and that it is aggregated with the air passenger prevalence data (although this information is not routinely collected). If some of the community members were higher risk (i.e. they were symptomatic) this would make Collinson's recorded prevalence higher than that of the community.

As data is not collected on the impact of community testing on Collinson's overall air passenger recorded prevalence, and LAMP/antigen tests are more likely to be administered to passengers staying in areas outside London, we benchmarked LAMP/antigen testing against England community prevalence. We also included a sensitivity analysis where we scaled England community prevalence by different assumptions around symptomatic passengers opting not to fly. We did this because the Cignpost data suggests that air passenger prevalence is lower than that of the community (due to a combination of factors, such as air passengers opting out of travel if they develop symptoms).

We compare the positivity rate from Collinson's LAMP and antigen pre-departure testing data to the age- and time-weighed positivity rates from the ONS Infection Survey for England (see Table 3.5). The data is restricted to before 15 January 2021 as on this date the Netherlands put in a policy where additional antigen testing was required at the airport after passengers had already received a negative PCR test result 72 hours pre-departure. Including data after 15 January 2021 would therefore bias downwards the prevalence detected via antigen testing. We assumed that air passengers would have a similar prevalence to that of England, as passengers from across the country fly out of Heathrow for many international destinations. We compared LAMP and antigen testing to age- and time-weighed positivity rates from London as a sensitivity analysis (see Appendix A5).

Table 3.5 Positivity rate of LAMP/antigen testing compared to PCR case positivity in the England community

Metric	Antigen			LAMP		
	Central	Lower	Upper	Central	Lower	Upper
Age-weighed ONS infection survey positivity rate (RT-PCR)	2.31%	2.07%	2.56%	1.81%	1.60%	2.04%
Collinson pre-departure positivity rate	0.97%	0.83%	1.13%	0.97%	0.83%	1.13%
Positivity rate compared to age-weighed ONS infection survey	**0.42**	**0.32**	**0.55**	**0.53**	**0.41**	**0.71**

Source: ONS Infection Survey and Collinson pre-departure testing data.

This shows that cases detected through antigen and LAMP testing are 42% and 53% of those expected from RT-PCR testing in the community. There are several potential explanations for this, including:

[43] 95% confidence interval 1.26–1.31%
[44] 95% confidence interval 1.99–3.33%

- air passengers practise social distancing pre-departure, because they do not want to contract COVID-19 and miss their flight, so there are fewer infected air passengers;
- the specific LAMP and antigen tests used are less sensitive than PCR tests. Our previous analysis highlighted that there are a range of different antigen tests, and while some have similar sensitivity to PCR tests, other antigen tests have much lower sensitivity. Therefore the type of antigen test used is an important determinant in how many cases will be detected;[45]
- air passengers choose not to fly if they develop symptoms consistent with COVID-19, so there are fewer symptomatic COVID-19 cases in air passengers compared to the overall population.[46]

Differences between the air passenger prevalence detected via LAMP/antigen testing compared to community PCR test positivity are likely to be due to a combination of the above factors. For example, if we scale the percentage of people in the community testing positive with a PCR test assuming that 20%[47] of passengers who become symptomatic pre-departure choose not to fly, antigen and LAMP test positivity rates are 47% and 60% that of PCR, respectively (see Table 3.6).

Table 3.6 Positivity rate of LAMP/antigen testing compared to PCR case positivity in the England community, assuming 20% of symptomatic passengers choose not to fly

Metric	Antigen			LAMP		
	Central	Lower	Upper	Central	Lower	Upper
Age-weighed ONS infection survey positivity rate (RT-PCR)	2.05%	1.84%	2.27%	1.61%	1.42%	1.81%
Collinson pre-departure positivity rate	0.97%	0.83%	1.13%	0.97%	0.83%	1.13%
Positivity rate compared to age-weighed ONS infection survey	**0.47**	**0.36**	**0.62**	**0.60**	**0.46**	**0.79**

Source: Oxera and Edge Health.

If we scale the percentage of people in the community testing positive with PCR tests assuming that 70%[48,49] of passengers who become symptomatic pre-departure choose not to fly, antigen and LAMP test positivity rate are 69% and 88% that of PCR, respectively (see Table 3.7).

[45] See Oxera and Edge Health (2021), 'Assessment of the effectiveness of rapid testing for SARS-CoV-2', 25 March. We were not able to find sufficient information about the type of antigen test used by Collinson to determine whether it was one with high reported sensitivity and specificity.
[46] In the Oxera and Edge Health report (2021) 'Assessing the effectiveness of dual testing strategies', 18 March, we assumed that 18.2–70% of infected travellers symptomatic at the time of departure voluntarily opted out of flying.
[47] Smith, L.E., Potts, H.W.W., Amlot, R., Fear, N.T., Michie, S. and Rubin, J. (2020), 'Adherence to the test, trace and isolate system: results from a time series of 21 nationally representative surveys in the UK' (the COVID-19 Rapid Survey of Adherence to Interventions and Responses [CORSAIR] study), September, https://doi.org/10.1101/2020.09.15.20191957
[48] Clifford et al. (2020), 'Strategies to reduce the risk of SARS-CoV-2 re-introduction from international travellers', 25 July.
[49] Gostic, K., Gomez, A.C., Mummah, R.O., Kucharski, A.J. and Lloyd-Smith, J.O. (2020), 'Estimated effectiveness of symptom and risk screening to prevent the spread of COVID-19', eLife, 24 February, http://dx.doi.org/10.7554/eLife.55570

Table 3.7 Positivity rate of LAMP/antigen testing compared to PCR case positivity in the England community, assuming 70% of symptomatic passengers opt not to fly

Metric	Antigen			LAMP		
	Central	Lower	Upper	Central	Lower	Upper
Age-weighed ONS infection survey positivity rate (RT-PCR)	1.40%	1.26%	1.56%	1.10%	0.97%	1.24%
Collinson pre-departure positivity rate	0.97%	0.83%	1.13%	0.97%	0.83%	1.13%
Positivity rate compared to age-weighed ONS infection survey	**0.69**	**0.53**	**0.90**	**0.88**	**0.67**	**1.16**

Source: Oxera and Edge Health.

Furthermore, as outlined in previous reports,[50] people can continue to test positive with a PCR test even when they are no longer infectious. People are less likely to test positive in their post-infectious window using other testing methodologies (e.g. antigen testing).[51] However, missing these positive cases does not affect onward transmission of the virus since these people are no longer infectious. We accounted for this in other modelling work on pre-departure test efficacy by measuring efficacy in terms of infectious days.[52]

[50] Oxera and Edge Health (2021), 'Assessment of the effectiveness of rapid testing for SARS-CoV-2', 25 March.
[51] This is also true for pre-infectious individuals.
[52] Oxera and Edge Health (2021), 'Effectiveness of dual-testing schemes for air passengers', 18 March; Oxera and Edge Health (2021), 'Assessment of the effectiveness of rapid testing for SARS-CoV-2', 25 March.

4 Testing implementation

As part of our study, we conducted interviews with Heathrow Airport and the airlines that participated in the trials to understand the operational factors associated with implementing different testing schemes that affect passengers and providers. We identified two main factors that are likely to affect operations in the aviation sector if testing remains in place as demand for air travel returns:[53]

- lack of consistent local and international standards;
- suitability of the existing infrastructure.

In this section, we describe these issues and illustrate their relevance based on discussions with Heathrow and the airlines.[54] At the end of the section, we discuss how these issues could affect passenger and provider (i.e. airport and airline) behaviour in the aviation market and how they could therefore act as a barrier to the recovery of air travel.

4.1 Lack of consistent local and international standards

A year into the pandemic, there is now more evidence on the extent to which different testing schemes are able to screen infected travellers. However, standard testing requirements for air travel have yet to be implemented even within a given region (e.g. the EU). Both testing requirements (test technology, test timing) and documentation of test results lack standardisation. There are also frequent changes in the requirements across countries. In this section, we outline the causes and implications of this lack of standardisation, and provide recommendations.

Passengers departing from the UK must meet different pre-departure testing requirements depending on their destination. Table 4.1 provides examples for departures from the UK to a number of destinations.

Table 4.1 Pre-departure testing requirements for departures from the UK to example North American and European destinations

Destination	Test timing(s)	Test type(s)
USA	Three days pre-departure	PCR or LAMP or antigen
Canada	Three days pre-departure	PCR or LAMP
Netherlands	Three days pre-departure and on departure	PCR and antigen
France	Three days pre-departure	PCR
Germany	Two days pre-departure	PCR or LAMP or antigen

Source: Oxera and Edge Health. Accurate as of 18 March 2021.

Differences between requirements across countries, and changes in these requirements, which sometimes occur with very short notice,[55] have a significant impact on passengers and providers in the aviation market. Combined with a lack of standardised documentation of test results, this can lead to:

[53] For example, as vaccines are administered in large numbers across multiple countries.
[54] Our analysis in this section is conditional on the widely accepted testing technologies at the time of this report: PCR, LAMP, antigen. The availability of improved testing technologies would alleviate some of the factors discussed in this section.
[55] Oxera and Edge Health (2021), 'Assessment of the JBC's methodology', 8 March.

- uncertainty for passengers in planning their travels;
- difficulty for providers in ensuring the current requirements are followed by their field agents in activities such as document verification;
- increased time for passengers at the airport due to document verification;[56]
- increased likelihood that a passenger may be denied boarding due to providing the wrong documentation or taking a test that is not accepted by the relevant country.[57]

Many of these factors lead to increased transaction times at the airport, which can make maintaining social distancing challenging. Box 4.1 sets out an example of a recent change in testing requirements for passengers travelling to the Netherlands to illustrate the challenges associated with changes to country-specific requirements.

Box 4.1 Changes to travel requirements

On 15 January 2021, the Netherlands introduced an additional pre-departure test requirement for passengers travelling to the Netherlands: an antigen test administered 12 hours before departure. Heathrow and other airports had less than 24 hours' notice from the government to implement testing and document screening for passengers travelling to the Netherlands.

This caused confusion for passengers. Passengers were unsure of the new type of test required and the short notice period gave passengers little time to prepare. For Heathrow, this led to a surge in demand for antigen testing, resulting in queues that made it more difficult to enforce social distancing.

Source: Oxera and Edge Health interviews with representatives from Heathrow and the airlines.

Interviewees considered that standardising air travel documentation would both reduce waiting times at the airport and alleviate concerns associated with document verification. Such standardisation could be achieved with COVID-status certification. In interviews, airlines mentioned that COVID-status certification provided by private organisations could be used to validate test results for their passengers.[58]

Differences in test type and timing of test requirements by destination also have implications for infrastructure requirements and on the testing market (discussed in section 4.2). For example, where tests are administered by professionals, requirements that tests be administered close to the time of departure mean that infrastructure for test centres needs to be close to the airport.[59] Where antigen tests are permitted, delivery models where air passengers self-administer tests while being supervised by a professional to validate the results (e.g. through video-conferencing) could help mitigate infrastructure requirements.

[56] For example, our interviews with some airline representatives suggested that the check-in process now takes two to three times longer due to country-specific document verification.
[57] We understand from some airline representatives that there have been many instances of denied boarding because a passenger has a valid negative test result but of a test type that is not accepted by the destination country.
[58] For example, AA/BA/oneworld referenced using the company VeriFLY, see: https://www.myverifly.com/#/
[59] Self-administering molecular tests and mailing results to a laboratory can help circumvent these infrastructure requirements, but even with self-administered tests, geography will continue to be a constraint the closer to departure the tests are administered.

4.2 Suitability of infrastructure

Depending on the test type and timing requirements, testing schemes will require different infrastructure to operationalise at scale.[60] In this section, we summarise infrastructure options by test timing and type (see Table 4.2) and discuss the benefits and challenges of each option (see Table 4.3).

Table 4.2 Infrastructure options by test timing and type

Test timing	Options	Test type	Description
D-72	Home testing	Molecular or antigen test	Provider mails the test to passenger. Passenger self-administers the test and mails it back to the lab. Passenger receives the test results digitally
	Local testing providers	Molecular or antigen test	Designated test provider, where testing for travel purposes is permitted
D=0	Home testing	Antigen test	Video conference, where provider observes passenger self-administering the antigen test. As antigen tests are rapid, provider can validate the test results on video
	Nearby testing facilities (e.g. car park)	LAMP or antigen test	Testing at facility close to the airport, but not at the terminal. Passenger awaits the results at the testing facility
	Travel hub (e.g. rail station) testing	LAMP or antigen test	Testing en route to the airport. Passenger awaits the results at the testing facility
	Terminal testing	LAMP or antigen test	Testing once passengers arrive at the airport terminal. Testing must be administered landside
A=0	Designated testing facilities	LAMP or antigen test	Incoming passengers bussed to designated facilities where they are subsequently tested
	Terminal testing	LAMP or antigen test	Testing once passengers arrive at the airport terminal. Testing can be administered landside or airside
A + post-arrival quarantine period	Home testing	Molecular or antigen tests	Provider mails the test to the passenger. Passenger self-administers the test and mails it back to the lab. Passenger receives the test results digitally.
	Local testing providers	Molecular or antigen tests	Designated test provider, where testing for travel purposes is permitted (and exceptions to quarantine for testing are permitted)

Source: Oxera and Edge Health.

Pre-departure or post-arrival tests are typically administered at local testing centres or self-administered at passenger accommodations.[61] The use of local testing centres requires infrastructure designed for administering tests, and storing and processing test results. Self-administered testing has fewer

[60] As of 15 February 2021, UK has introduced a hotel quarantine scheme for arrivals from some red list countries. We do not evaluate the operational considerations arising from such quarantine schemes in this report. More information on the scheme is available at Department of Health and Social Care (2021), 'Booking and staying in a quarantine hotel when you arrive in England', Guidance, https://www.gov.uk/guidance/booking-and-staying-in-a-quarantine-hotel-when-you-arrive-in-england, accessed 16 February 2021.

[61] For most types of tests (e.g. PCR, LAMP, antigen), it may also be possible to use self-administered home test kits mailed to a passenger's address at their origin or provided to them at their arrival airport.

infrastructure requirements, although lab facilities are still required where molecular (PCR, LAMP) tests are used.

On-departure and on-arrival testing can be administered centrally at designated landside areas at an airport or near the airport (e.g. in a car park).[62] If antigen tests are used, on-departure testing can also be conducted at home.[63] On-site testing reduces the difficulties that a passenger may face in accessing a relevant test type for a particular destination at local testing centres.[64] However, airport testing creates infrastructure challenges as landside areas are designed for passenger flow rather than for passengers to gather in large numbers.[65] It is also not possible to administer tests (e.g. PCR) with longer turnaround times in these settings.[66]

Our interviews with representatives from Heathrow and the airlines taking part in the trials indicated that the lack of space at airports introduces challenges in administering tests, even with the current low number of passengers.[67] Therefore, to provide additional capacity, some testing is performed at a drive-through testing centre in the vicinity of the airport.[68] Even with this additional capacity, providing testing at scale as passenger numbers return would be challenging. Box 4.2 discusses how the mismatch between airport design and testing requirements can affect the passenger and provider experience.

Box 4.2 Airport terminal design and testing requirements

On-departure testing at Heathrow is currently administered at Terminals 2 and 5. Heathrow also provides testing at a car-park facility for pre-departure tests and the test-to-release scheme. Providing testing at the terminal has been challenging as airports are designed for passenger flow, not to maximise landside space. In Terminal 2, Heathrow has been able to use recently vacated existing space, but in Terminal 5 they have had to create a purpose-built space.

Despite low current passenger volumes, space constraints still make it difficult to deal with spikes in demand. Limited space in terminals can make social distancing challenging during these spikes. Setting up booking systems so that tests are primarily pre-booked could help to manage these spikes—someone who has pre-booked (and registered their details online) takes roughly 60–90 seconds to register at the test centre while a walk-in can take five to ten minutes to register.

However, space constraints mean that testing at terminals could not support increased passenger volumes as demand for travel recovers.

Source: Oxera and Edge Health interviews with representatives from Heathrow and the airlines.

Table 4.3 below summarises the benefits and challenges associated with digital, distributed, and centralised testing.

[62] This takes place before passengers start their check-in processes at landside areas.
[63] With supervision via video-conferencing, right before the passenger travels to the airport.
[64] Assuming that the relevant test is administered at the airport.
[65] Gathering large numbers of people for testing at the airports before departure or after arrival may also introduce public health challenges if social distancing rules cannot be followed or if passengers travelling from/to different destinations mix with each other due to a lack of space.
[66] For example, results from a PCR test are usually available within 24 hours. If a departing traveller requires a PCR test, and the test is provided at the airport instead of locally, the traveller would have to travel to the airport for the test a few days before their date of departure and again as a part of their journey.
[67] In December 2020, approximately 1.1m passengers travelled through Heathrow Airport. This is 17% of the number of passengers in December 2019. For more information, see Civil Aviation Authority, 'UK airport data', https://www.caa.co.uk/Data-and-analysis/UK-aviation-market/Airports/Datasets/UK-airport-data/, accessed 16 February 2021.
[68] For details, see Heathrow Airport, 'COVID-19 Test for Travel', https://www.heathrow.com/at-the-airport/fly-safe/covid-19-test, accessed 16 February 2021.

Table 4.3 Benefits and challenges of different types of testing infrastructure

	Distributed to local centres	Centralised at the airport
Benefits	Allows passengers to arrange testing at an appropriate time. Makes use of multiple sites designed specifically for testing.	Able to provide services to all passengers from a central location.
Challenges	Not all passengers have access to a testing centre locally. May not be possible to book a slot for testing if the scheme requires testing a short time before departure or after arrival.	Risks untested passengers from different origins mixing with each other. Infrastructure at airports is not designed for testing activities.

Source: Oxera and Edge Health analysis.

Despite providing benefits to passengers in terms of access to testing, the challenges described in Box 4.2 above show that centralised testing at the airport would act as a constraint to the resumption of higher levels of air travel with the current infrastructure. More specifically, it would act as a capacity constraint on the aviation market. We discuss how capacity constraints affect the aviation market below in section 4.3.

For on-departure testing, interviewees considered that optimal testing strategies would combine the benefits of distributed and centralised testing while eliminating the challenges as much as practically possible. Even though the optimal approach depends on the test type, the following considerations may broadly apply:

- where antigen tests are permitted by countries for pre-departure tests, video-conferencing could be used to allow passengers to self-administer tests under supervision close to the time of departure;
- designing test centres along the main transport lines to and from airports could give testing providers more opportunities to allocate space for testing activities and to continue providing centralised options for air travellers if they cannot get them locally;[69]
- integrating tests into a traveller's journey, for example at transport hubs.

We note that these different test types and options are likely to have different costs associated with them. For example, antigen tests are typically significantly less expensive than PCR tests. Therefore, the option selected may have implications for the cost of travel for passengers, and consequently the resumption of air travel.[70]

4.3 Impacts on passengers and providers

The operational factors discussed above would affect passengers and providers in the aviation market, either by increasing travel costs (monetary or non-monetary) or by reducing airport capacity. The Department for Transport's (DfT) guidance on aviation appraisal provides a framework to assess the

[69] Testing in the vicinity of the airport as currently performed by Heathrow is an example that carries the benefits of centralised testing for passengers travelling with private transport and lessens the challenges introduced by a lack of space at the landside. However, as demand for air travel increases, it is plausible to assume that demand for public transport would also increase, making drive-through testing centres on average less relevant for air travellers.
[70] See: Oxera and Edge Health (2021), 'Assessment of the effectiveness of rapid testing for SARS-CoV-2', 25 March.

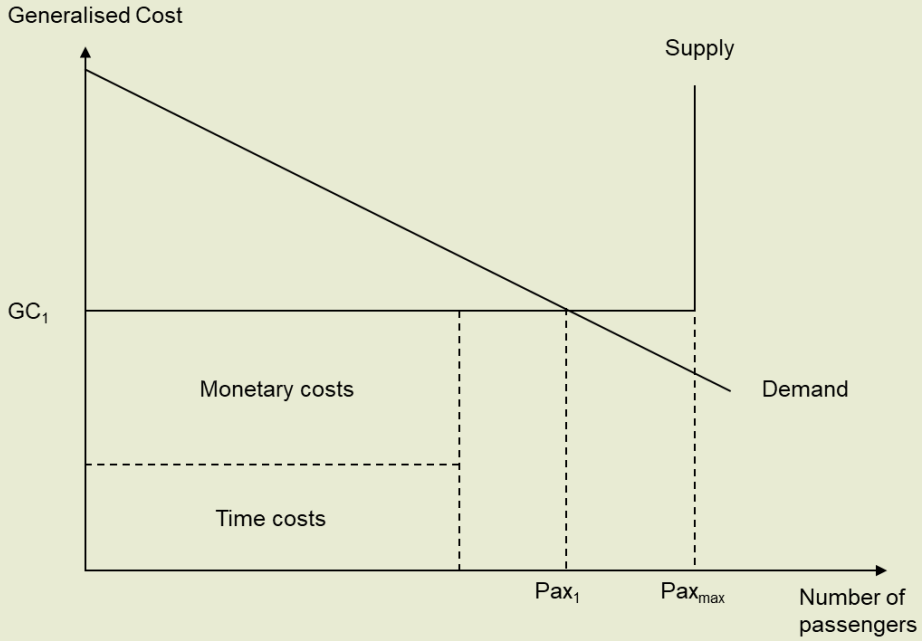
impacts of these changes on the aviation market,[71] as summarised in the box below.

Box 4.3 DfT's approach to aviation appraisal

The DfT's analytical framework for assessing the impact of policies on the aviation market was developed as a stylised interaction between passengers and providers (airports and airlines). The diagram below illustrates how this interaction determines the market outcomes, taking account of the additional costs to passengers and restricted capacity of providers.

In this diagram, passenger behaviour is illustrated with a downward-sloping linear curve to represent increasing numbers of passengers at lower generalised travel costs.[1] The rotated L-shaped supply curve illustrates that airlines can provide seats up to the capacity provided by airports (Pax_{max}). The current market equilibrium (prevailing market prices and number of passengers) is illustrated by the intersection of supply and demand curves (at GC_1 and Pax_1). Factors affecting the supply of aviation services would affect the market outcome through the supply curve and factors affecting demand for aviation services would affect the market outcome through the demand curve, resulting in a new equilibrium.

Figure 4.1 Aviation market framework



Note: The stylised framework assumes that the supply of seats by airlines is enough to provide aviation services up to the capacity that airports can provide. The diagram illustrates an initial scenario without airport capacity constraints, i.e. there are enough air services to accommodate the demand at Pax_1. Under normal travel conditions, some UK airports are capacity-constrained.[2] However, this does not affect the direction of the impacts described in this section.

Source: Based on Department for Transport (2018), 'TAG UNIT A5.2 Aviation Appraisal', Appendix A, pp.11–12.

Note: [1] Generalised cost represents the expected sum of monetary costs and monetised time costs that a passenger incurs to complete their travel. [2] Department for Transport (2018) 'TAG UNIT A5.2 Aviation Appraisal', Appendix A, p.12.

Source: Oxera and Edge Health analysis.

The cost of testing—i.e. the monetary costs as well as the increased time spent organising and taking the tests—and uncertainty regarding changing travel restrictions are both factors that increase the generalised cost of travel for an air passenger. These would cause an increase in the sum of monetary

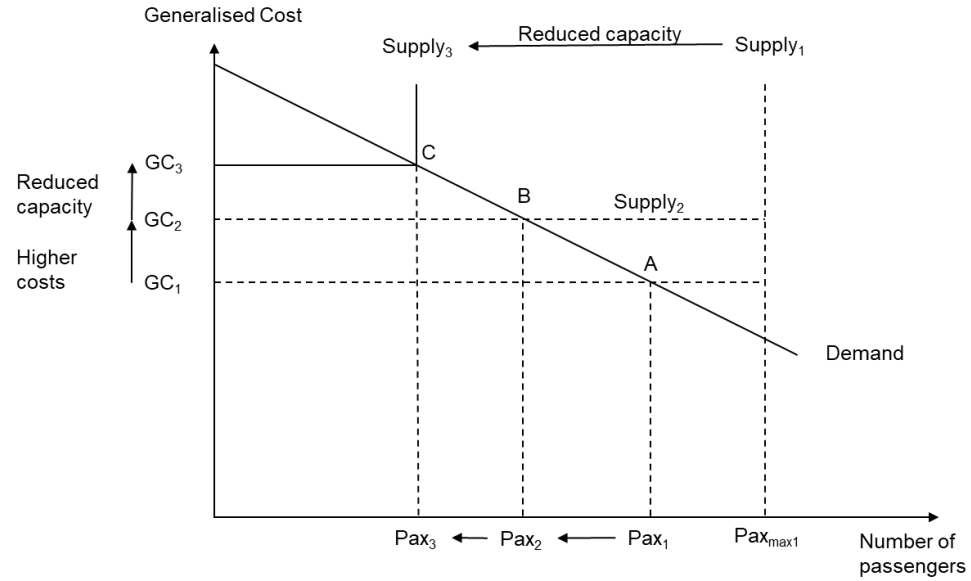
[71] Department for Transport (2018), 'TAG UNIT A5.2 Aviation Appraisal', May.

and time costs, resulting in a higher equilibrium price in the aviation market while testing is in place even when demand for air travel starts to return.

Lack of capacity and time at airports to administer and verify tests would effectively limit airports' capacity to provide services to passengers, shifting the supply curve inwards. The impact of this reduction in capacity on the aviation market depends on whether the reduced capacity is lower than the demand in the market.[72]

Figure 4.2 illustrates a new market equilibrium with the new costs and capacity constraints. In this figure, the market equilibrium for air travel is represented by point A.[73] The additional testing costs associated with air travel increase average costs from GC_1 to GC_2. If operational factors have no impact on airport capacity, or if the reduced capacity is above the passenger demand at the new market price GC_2,[74] the market equilibrium moves to point B from point A, resulting in an aviation market with higher prices and lower demand.[75] If, in addition to increases in monetary and non-monetary costs, operational factors affect the airport capacity to a level below demand for air travel, this limits the number of passengers who can use aviation services, further increasing prices in the market and limiting air traffic. This new equilibrium is represented by point C.[76]

Figure 4.2 Impact of operational factors on the aviation market



Source: Oxera and Edge Health analysis.

It is likely that any testing scheme will create costs for passengers and affect the operations of airlines and airports. However, ensuring that there is sufficient and easily accessible capacity for testing, at the lowest cost possible,

[72] Considering that the operational challenges illustrated in Box 4.1 and Box 4.2 are experienced with the current low demand market situation, it is plausible to expect that the operational challenges, if unaddressed, would materially restrict capacity beyond the demand for air travel.
[73] Point A represents a scenario without testing where travel recovers.
[74] The capacity-unrestricted demand with the new costs is represented by Pax_2.
[75] In particular, the passengers who are crowded out of the aviation system would be those who cannot afford to travel in the new higher cost equilibrium points.
[76] The capacity-restricted demand with the new costs is represented by Pax_3. The additional costs represented as the difference between GC_2 and GC_3 are called the shadow costs of the capacity constraints on the aviation market. For more information, see Department for Transport (2018), 'TAG UNIT A5.2 Aviation Appraisal', Appendix A, paras A.1.4 and A.1.5, p. 12.

would allow the aviation market to end up at an equilibrium closer to its initial position as demand starts to return.

5 Conclusion

Our analysis of evidence from airline trials at Heathrow Airport suggests that pre-departure testing is an effective means of identifying COVID-19 among air passengers. The evidence from the AA/BA/**one**world trial indicates that 74% of infections are identified by pre-departure testing. This is consistent with evidence from the Toronto Pearson study and evidence from our modelling on the effectiveness of a single test in detecting COVID-19.

The relative efficacy of LAMP and antigen testing compared to PCR requires further analysis of underlying factors and more extensive data collection. Depending on assumptions around the proportion of symptomatic air passengers choosing not to fly due to symptoms,[77] we estimate that antigen testing screens between 42% and 69% as many infectious days as PCR testing, and LAMP testing screens between 53% and 88% as many infectious days as PCR testing. However, we note that the particular type of antigen test used can have a significant impact on the effectiveness of the test in detecting cases of COVID-19, and therefore if a different antigen test were used, it is possible that the efficacy of antigen testing could be higher.

Another potential reason for a smaller proportion of cases being identified via LAMP/antigen testing compared to PCR is that individuals may continue to test positive with a PCR test even after they are no longer infectious, whereas they are less likely to do so with LAMP/antigen testing technology. Not capturing these cases would have no impact on secondary infections from travellers, as they are no longer infectious. Further studies where the same passengers are administered PCR, LAMP, and antigen testing would help provide more definitive evidence on the relative efficacy of each of these testing methodologies.

The operational factors involved in implementing testing schemes are also critical to consider. To the extent that different countries can streamline testing and documentation requirements, this would increase efficiency for airports and airlines and improve the passenger experience. Solutions such as digital health wallets can help streamline check-in and mitigate the increased waiting times that result from additional document-checking requirements.

Testing schemes where tests can be administered at home rather than at the airport are also easier to operationalise. If governments require tests to be administered close to the time of departure, antigen tests could be self-administered at home with virtual supervision before travelling to the airport. This also has the benefit of ensuring that someone who tests positive does not travel to the airport.

As vaccines are rolled out and the UK population is increasingly protected, the risk of importing infections will decrease. This means that while testing schemes may be necessary in the short to medium term, in the long term, vaccines may allow us to return to a pre-COVID-19 situation in which testing is not regularly used in travel settings, and, when it is, it focuses on high-risk countries to provide additional protection against importing variants of concern.

[77] As data on rebooking patterns by reason for rebooking is unavailable, it is difficult to assess definitively the proportion of air passengers opting out of flying due to symptoms consistent with COVID-19. However, rebooking data does show trends consistent with passengers rebooking travel due to COVID-19 symptoms. However, these trends are equally consistent with changes in airline rebooking regulations and increased uncertainty in government travel regulations.

A1 Interview questions on operational issues

The questions used for interviews with Heathrow Airport and airlines are reproduced below.

1. Could you provide a brief description of testing regimes your organisation had to operationalise, not just during the trials but also as a part of the travel policies implemented in various jurisdictions so far?

2. Of the testing regimes mentioned above:

    a. which one was the most straightforward to implement from an operational perspective? What factors differentiated this regime from the others?

    b. which one was the most difficult to implement from an operational perspective? What operational issues made this regime difficult to implement?

3. How does the speed of a test, both in terms of time to administer the test and the time until results are available, affect your operation? Does the timing of the test, for example three days before departure, affect the relationship between speed and operability? Have you had any challenges with verifying that tests have been completed three days prior to departure?

4. If required, e.g. due to stricter testing requirements, are you able to easily access more tests? Does this depend on the test type?

5. What factors in the implementation of various tests, for example PCR, LAMP, or antigen, create logistical issues (such as storage, delivery, or space in the airport)? How does the timing of the test, for example on arrival, affect this? Could you give an example of one logistical challenge you had to solve to make a testing scheme operational?

6. Have you had any difficulty in accessing labour with required skills to implement any testing scheme? If this has been an issue, would the solutions you have developed be sufficient to operationalise the scheme at scale? Does your answer depend on the type of the test administered?

7. What are some other operational challenges in testing schemes that affect passenger, airline, and airport behaviour that would result in an increase in travel time, for example increasing time spent at the airport?

8. A number of governments around the world have put different testing schemes in place. Do differences in these schemes, for example accepting different types of tests, create operational difficulties? If so, how are you dealing with these difficulties?

9. Considering the current state of various testing schemes in place, how easily you can readjust your operation if a country changes some aspects of their testing policy (e.g. puts more stringent requirements in place)? Are there particular aspects of a testing policy that is more difficult to adjust than the others, such as a change in test or test timing?

10. Do you have any observations on how passengers reacted to different testing schemes? Could you provide some examples of the behaviour you observed or the feedback you received? Does your answer depend on the type of the test?

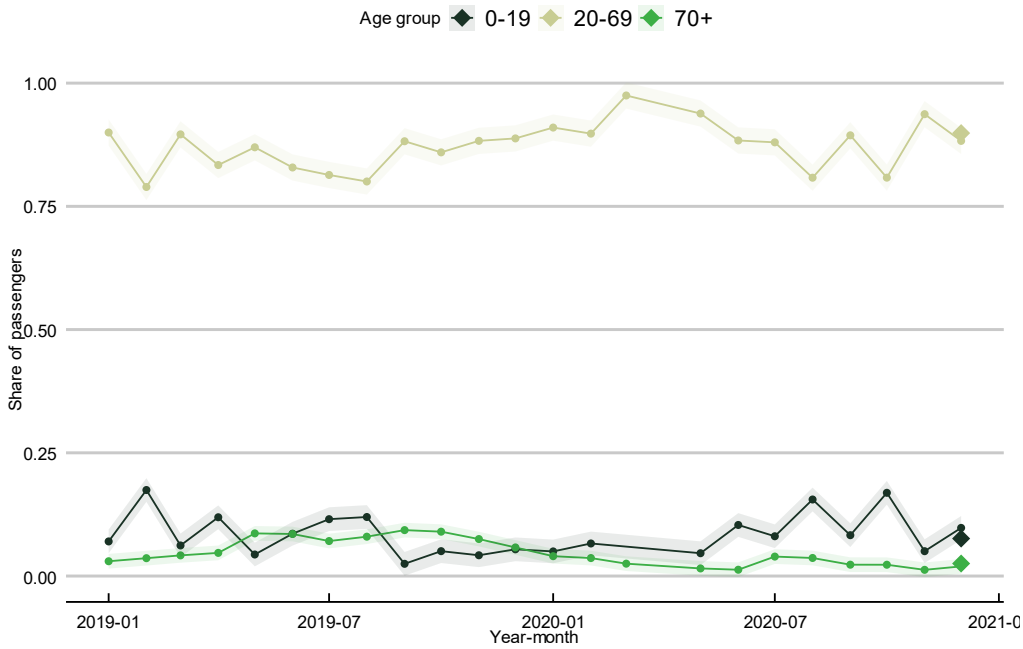
A2 Trial population demographics compared to the overall air passenger population

We have analysed demographic information on the routes where trials were implemented. This information is helpful to observe the differences between the historical travelling population and the current travelling population, as well as between the current travelling population and the trial participants where possible on the trial routes.

The analysis below suggests that, despite fluctuations over time, differences between the historical travelling population, the travelling population at the time of the trials, and the trial participants are small and mostly immaterial. However, we have only limited information on the observable demographics of passengers. Some information that may affect prevalence rates, such as income levels, is not available. In this sense, the demographic analysis presented below provides only partial evidence for generalising the trial outcomes to the passenger population during the time of the trial or to the typical passenger population.

A2.1 United Airlines trial

Figure A2.1 United Airlines trial: age bands

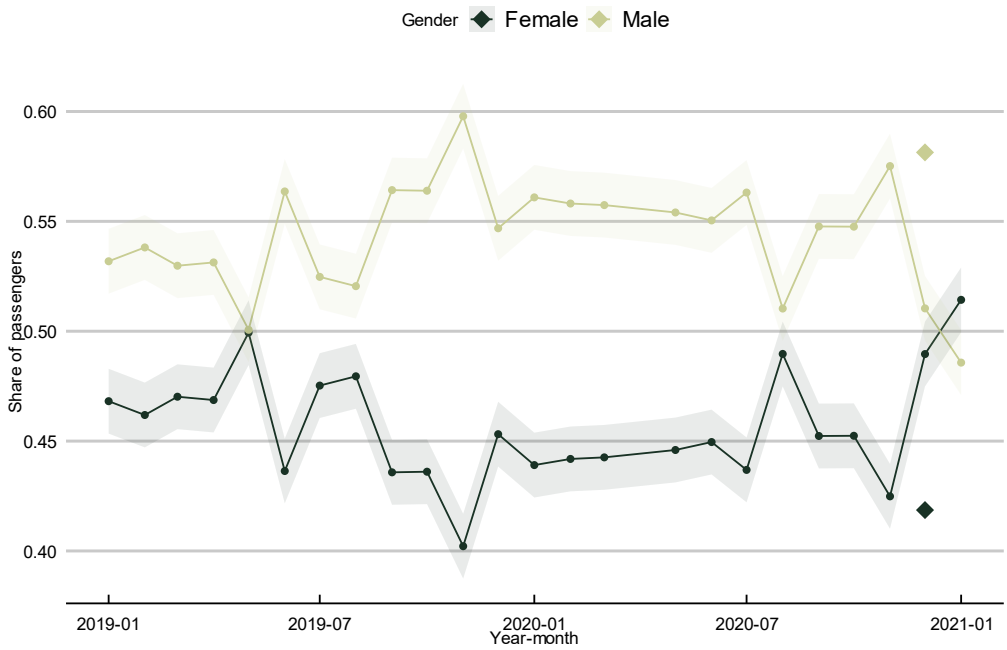


Note: Diamonds represent averages for the trial population.

Source: Oxera and Edge Health based on data from United Airlines.

A comparison of age bands suggests that the share of working age population was broadly consistent over time. In 2020, there was a slight increase in the share of younger travellers and a slight decrease in the share of older travellers. Shares of age groups in the trial population are similar to the shares in the overall traveller group at the time of the trial and to the historical averages.

Figure A2.2 United Airlines trial: gender



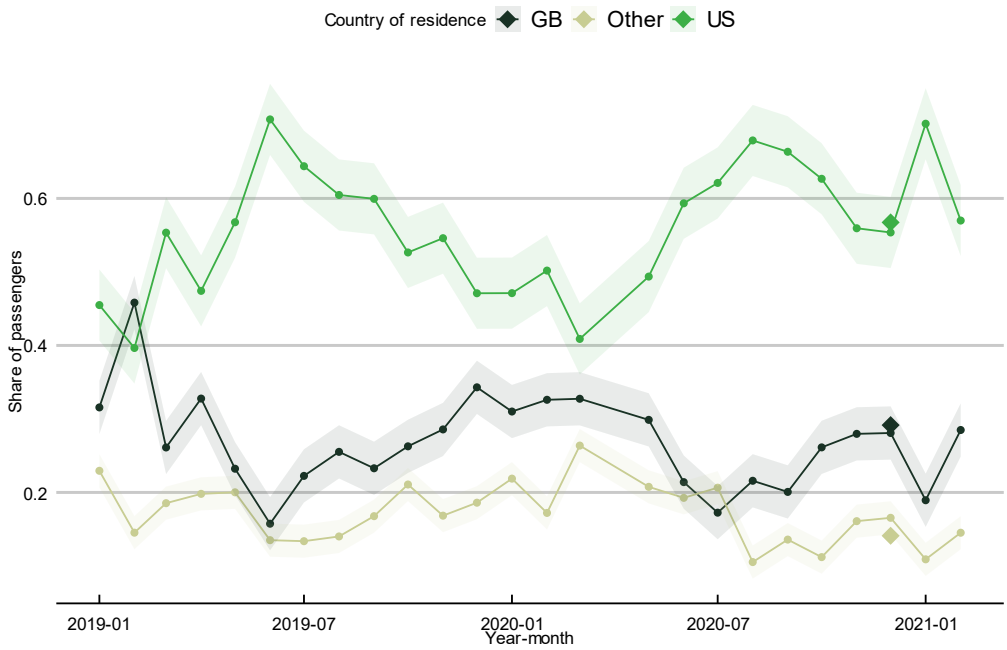
Note: Diamonds represent averages for the trial population.

Source: Oxera and Edge Health based on data from United Airlines.

We observe a slight increase in the average share of male passengers among air travellers in the first half of 2020. The shares in the second half of 2020 were similar to those in the second half of 2019. Even though shares for the trial participants were similar to 2020 averages, there was a significant increase in the share of female passengers in December 2020, which continued in January 2021. As a result, female passengers were under-represented by a few percentage points in the trial population.[78]

[78] The trial timing does not exactly overlap with monthly counts, as the trial took place from mid-November to early December 2020. In contrast, historical data provides information on monthly average shares. The gender shares in the trial population were similar to those in November 2020, as such under-representation, if any, is likely to be less than visually illustrated.

Figure A2.3 United Airlines trial: country of residence



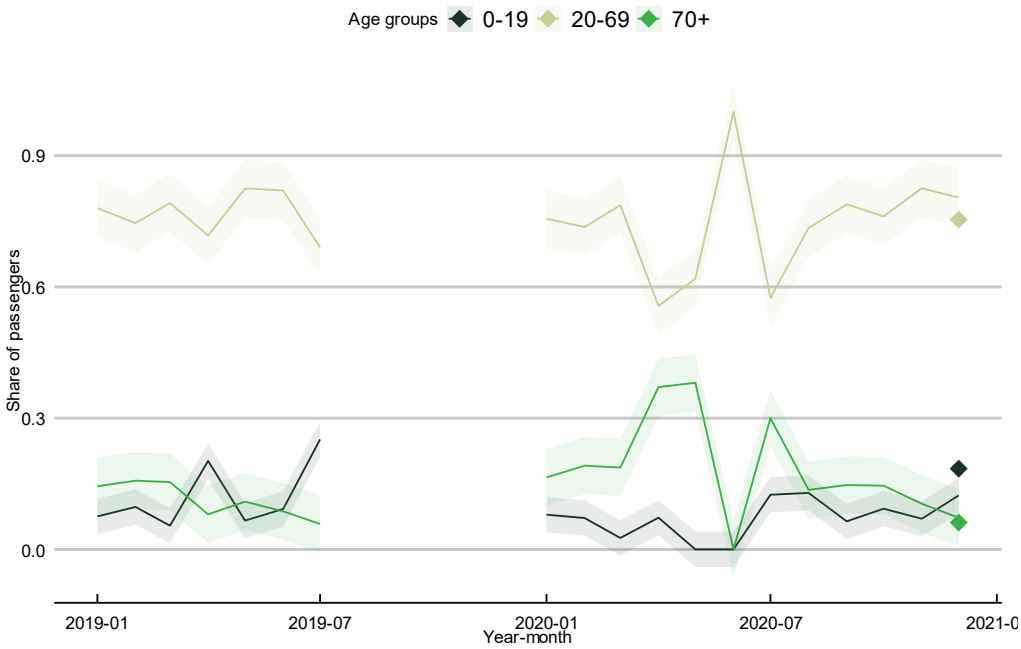
Note: Diamonds represent averages for the trial population.

Source: Oxera and Edge Health based on data from United Airlines.

On average, the share of US travellers was slightly higher in 2020 than in 2019. Shares of US passengers in the trial population are similar to the shares of the travelling population during the trial period and to the average in 2020.

A2.2 Virgin Atlantic trial

Figure A2.4 Virgin Atlantic trial: age bands

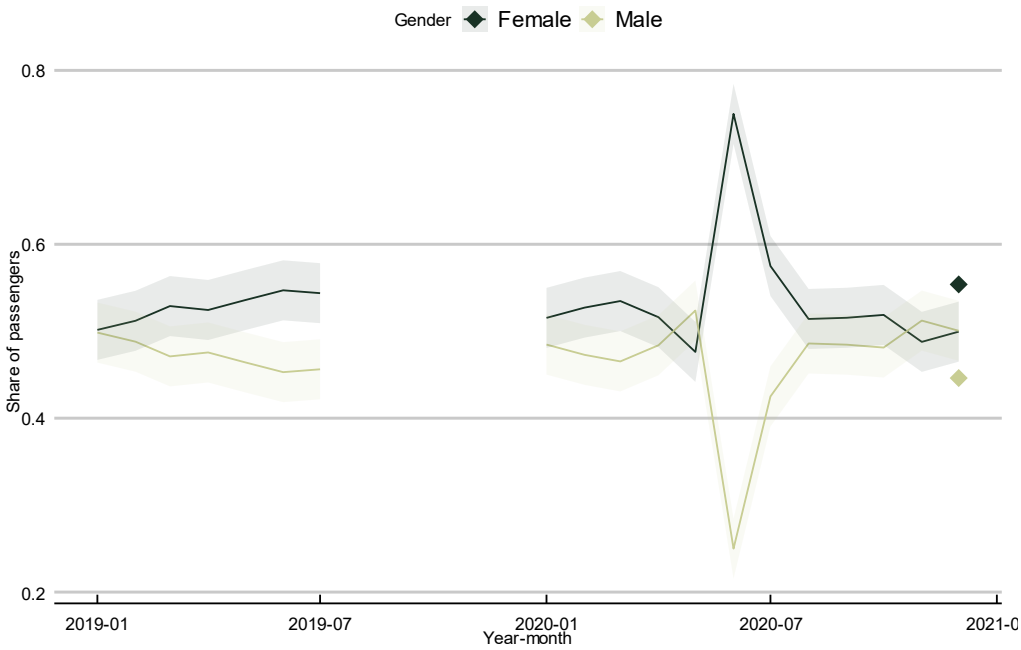


Note: Diamonds represent averages for the trial population. Data is not available from July 2019 to January 2020.

Source: Oxera and Edge Health based on data from Virgin Atlantic.

Shares of different age groups were stable over time, except for some fluctuations during the summer season. Young passengers were slightly over-represented in the trial population.

Figure A2.5 Virgin Atlantic trial: gender

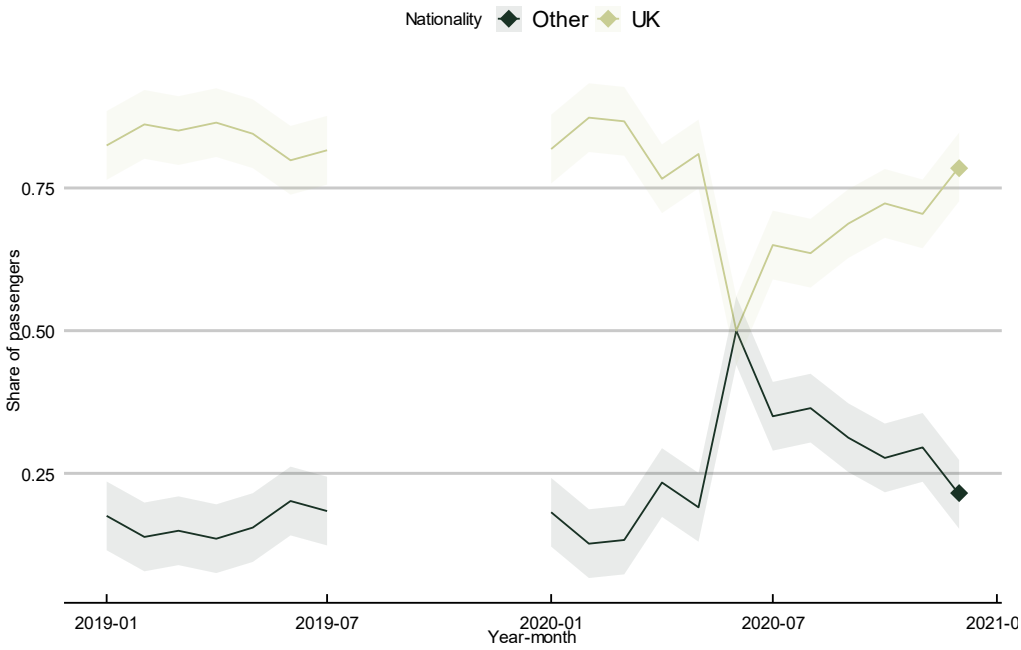


Note: Diamonds represent averages for the trial population. Data is not available from July 2019 to January 2020.

Source: Oxera and Edge Health based on data from Virgin Atlantic.

Shares of different genders were stable over time, except for some fluctuations during the summer season. Female passengers were slightly over-represented in the trial population.

Figure A2.6 Virgin Atlantic trial: nationality



Note: Diamonds represent averages for the trial population. Data is not available from July 2019 to January 2020.

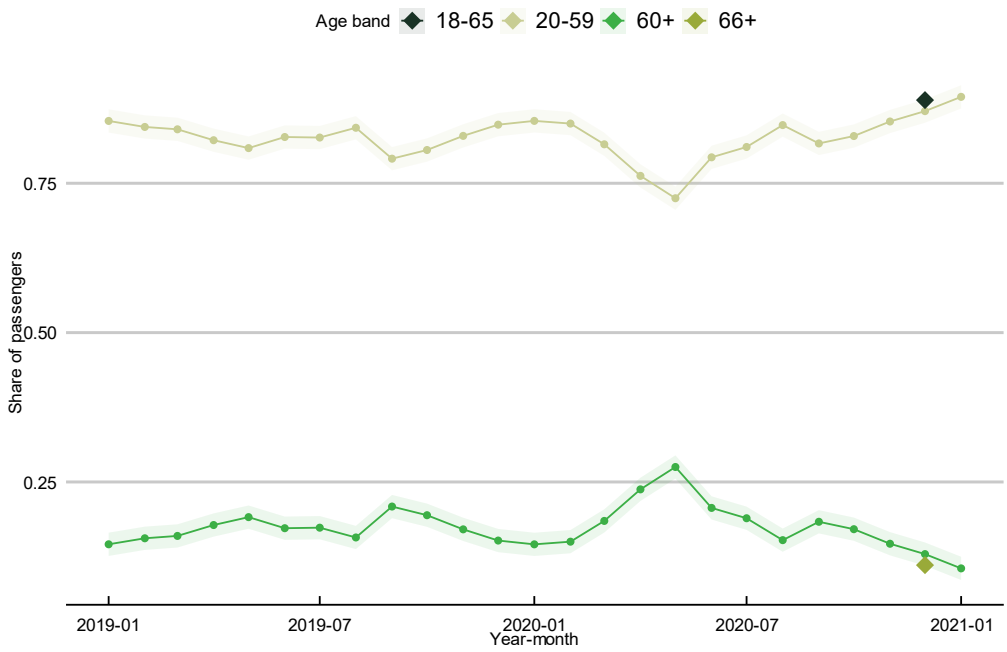
Source: Oxera and Edge Health based on data from Virgin Atlantic.

We observe a significant increase in the share of travellers from other nationalities in June. Shares of each nationality group returned to 2019 averages at the time of the trial. Nationality of the trial participants was similar to the wider travelling population at the time of the trial, and to the averages in 2019 and early 2020.

A2.3 AA/BA/oneworld trial

We note that not all of the data included below was taken from the trial conducted. Some of the analysis compares general AA/BA data from 2019 to 2020.

Figure A2.7 AA/BA/oneworld: age bands

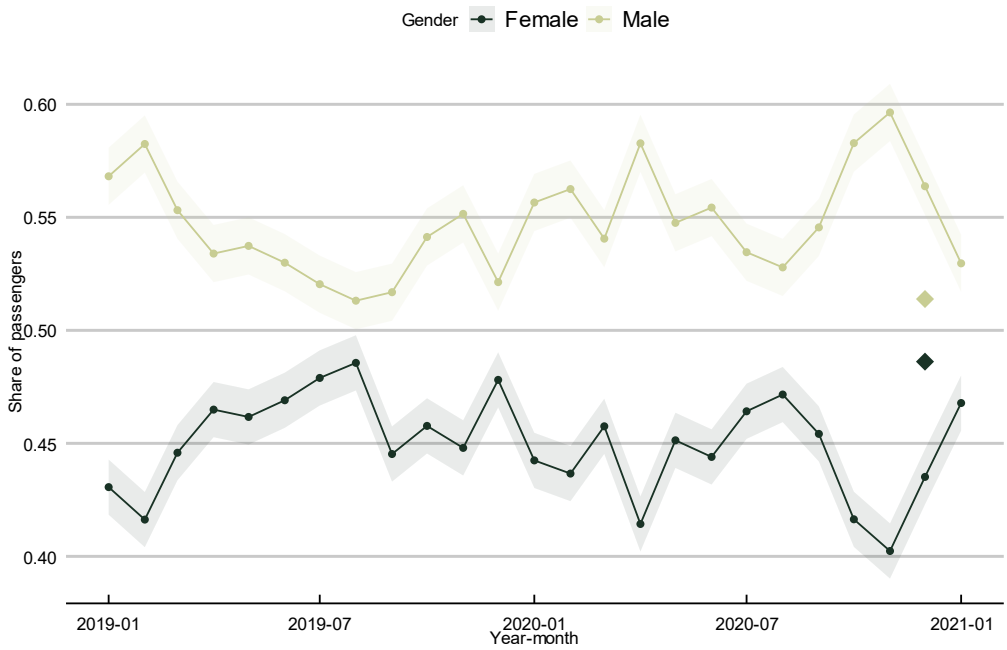


Note: Diamonds represent averages for the trial population.

Source: Oxera and Edge Health based on data from AA/BA/oneworld

A comparison of age bands is not straightforward as the age band groups in the demographic data and the trial data do not match. To match the groups as far as possible, we aggregated the age bands in historical data to two groups: 20–59 and 60+, and the age bands in the trial data to two groups: 18–65 and 66+. Based on these groupings, the share of working age travellers was consistent over time and the trial participants were not significantly different from the shares in the travelling population at the time of the trial.

Figure A2.8 AA/BA/oneworld: gender

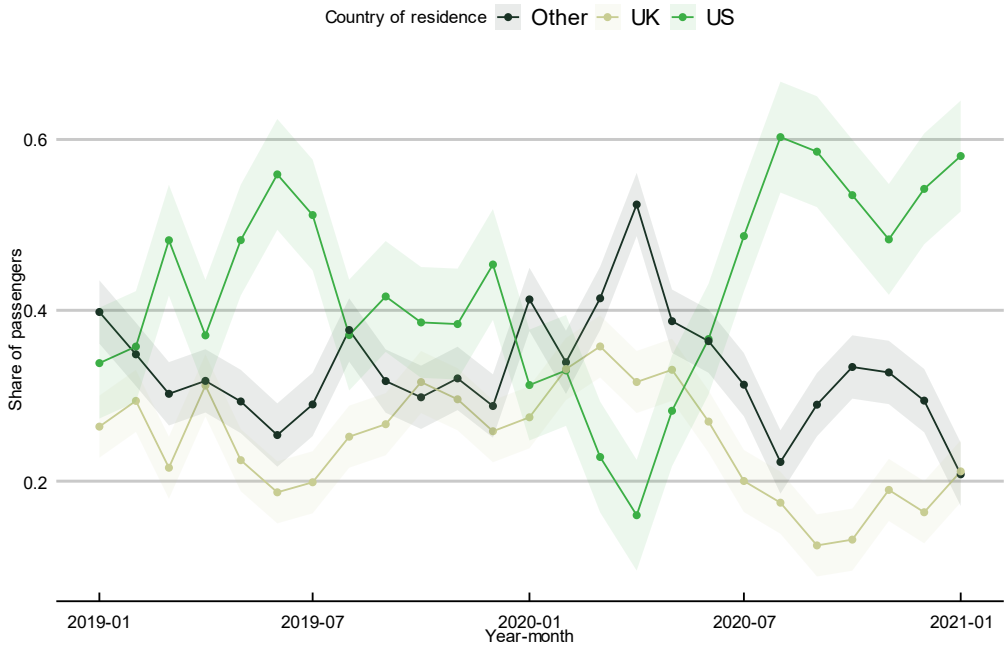


Note: Diamonds represent averages for the trial population.

Source: Oxera and Edge Health based on data from AA/BA/oneworld.

Gender shares among passengers were broadly consistent over time, with a slight increase in the average share of male passengers in 2020. Male passengers were under-represented by few percentage points.

Figure A2.9 AA/BA/oneworld: country of residence

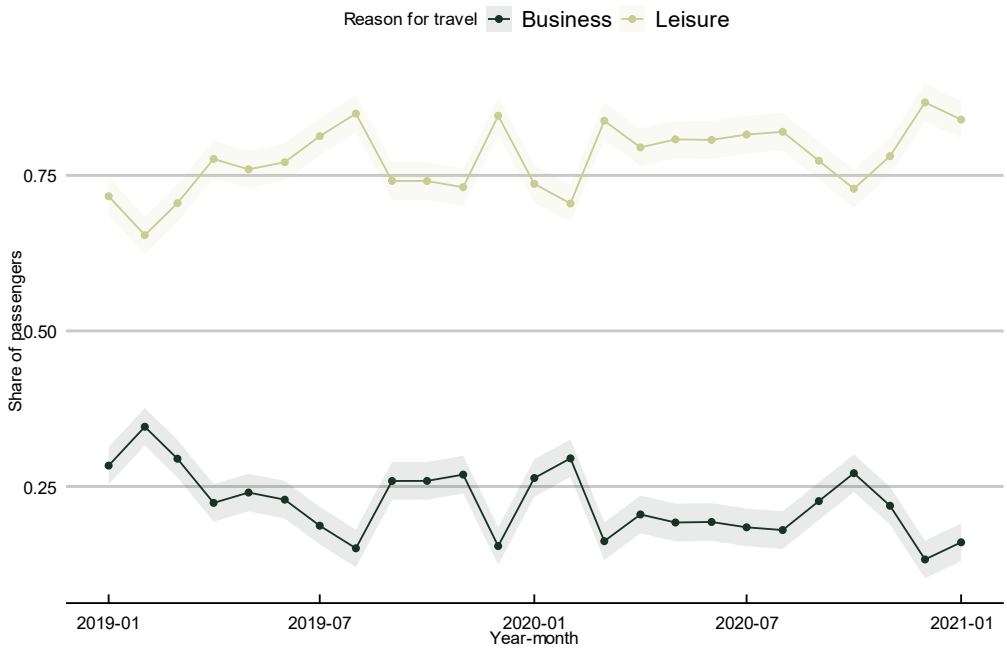


Note: Data for the trial population is not available for this category, therefore this is based on (non-trial) data from AA and BA.

Source: Oxera and Edge Health based on data from AA and BA.

US travellers are the dominant travellers on these routes, both historically and currently, except for a fluctuation during the first half of 2020. UK travellers are under-represented in the traveller population and travellers from other countries are over-represented compared to the 2019 average. We do not have information on the trial population for this demographic category.

Figure A2.10 AA/BA/oneworld: reason for travel



Note: Data for the trial population is not available for this category, therefore this is based on (non-trial) data from AA and BA.

Source: Oxera and Edge Health based on data from AA and BA.

Average shares of leisure and business travellers were broadly stable over time, resulting in similar average shares in 2019 and 2020. We do not have information on the trial population for this demographic category.

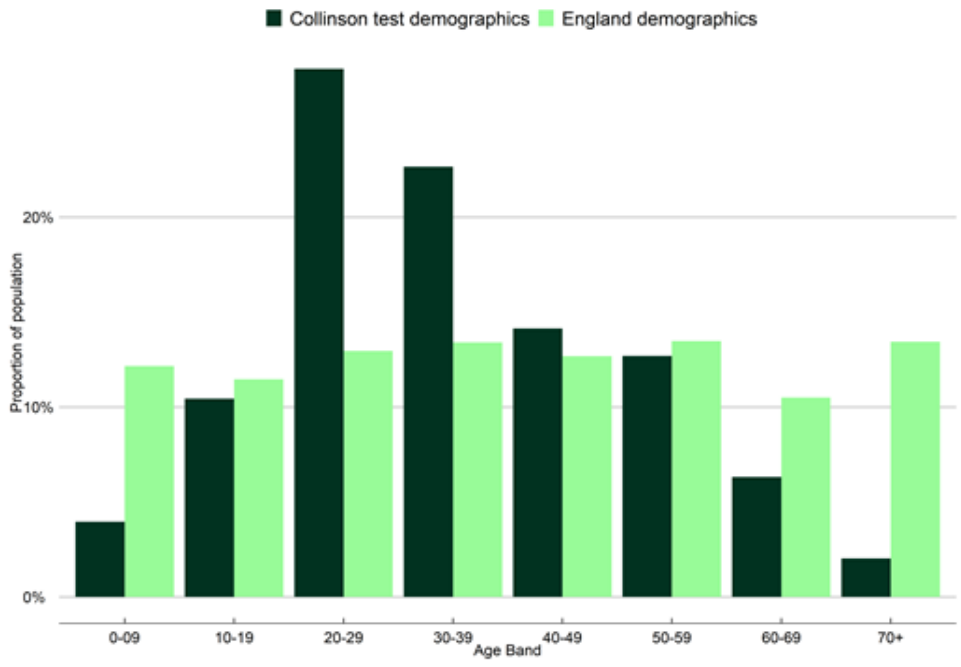
A3 Demographics compared to the country of origin

For the datasets where we compared infection prevalence directly to that of the community in the country of origin, we also compared the age distribution to that of the community to account for demographic differences that might drive prevalence differences.

A3.1 Comparison of Collinson testing data demographics to England population pyramid

As shown in the figure below, the population tested pre-departure by Collinson had fewer elderly individuals and children compared to the England population.

Figure A3.1 Comparison of England demographics to Collinson pre-departure testing population

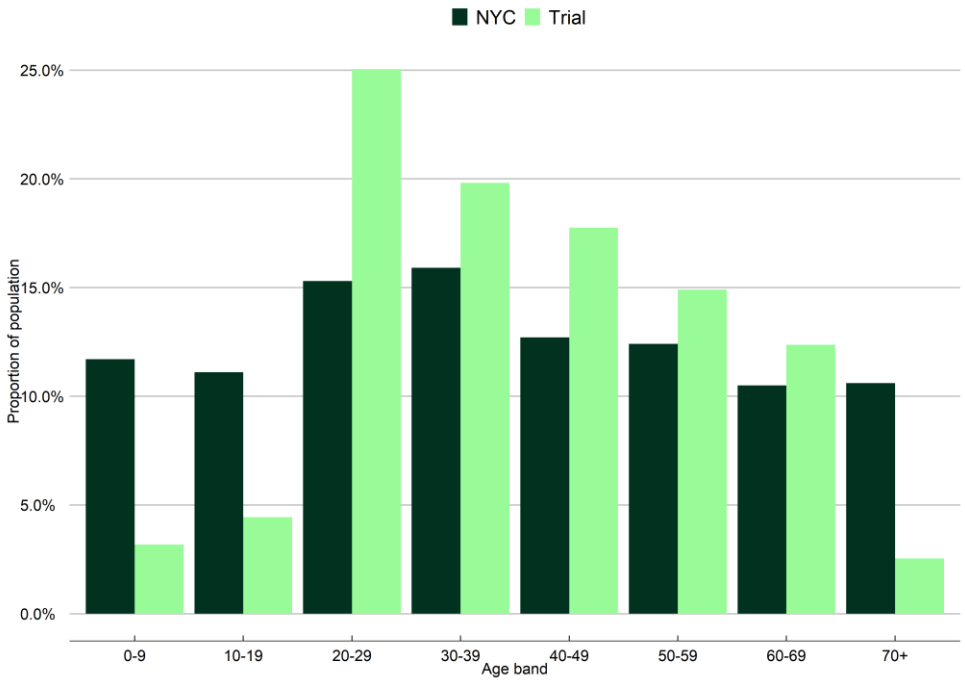


Source: Oxera and Edge Health.

A3.2 Comparison of United Airlines trial demographics with population pyramid of New York City

As shown in Figure A3.2 below, the population tested pre-departure by United Airlines had fewer elderly individuals and children compared to the population of New York City.

Figure A3.2 Comparison of New York City demographics to United Airlines on-departure testing population



Source: Oxera and Edge Health.

A4 Additional rebooking data analysis

We used the same criteria to analyse rebooking for the Virgin Atlantic trial as we used for the AA/BA/**one**world trial. We observed that self-selection into the trial represented 19% of rebooking from out of the trial. As there was only one flight in the Virgin Atlantic trial, we cannot comment on self-selection from the trial flights as passengers did not have the option to select onto another trial flight.

Table A4.1 Self-selection into trial—Virgin Atlantic

	…to out of trial	**…to in trial**	**Total**
From out of trial…	194 (**81%**)	45 (**19%**)	239
From in trial…	3 (**100%**)	0 (**0%**)	3
Total	197	45	242

Note: 'From out of trial…to out of trial' represents passengers whose initial bookings were on a non-trial flight and whose rebookings were on a non-trial flight. 'From in trial…to in trial' represents passengers whose initial bookings were on a trial flight and whose rebookings were on another trial flight. The other conditions represent movements from non-trial flights to trial flights or vice versa. Percentages represent row-wise proportions, for example 19% of passengers who changed their flight date from a non-trial flight rebooked on a trial flight. There was only one flight in the Virgin Atalntic trial. As such, passengers whose initial booking was on a trial flight would not be able to rebook on a trial flight.

A5 London prevalence sensitivity analysis

Table A5.1 Comparison of Collinson pre-departure antigen and LAMP testing to London community PCR test positivity

Metric	Antigen			LAMP		
	Central	Lower	Upper	Central	Lower	Upper
Age-weighed ONS Infection Survey positivity rate (RT-PCR)	3.35%	2.81%	3.95%	2.93%	2.40%	3.54%
Collinson pre-departure positivity rate	0.97%	0.83%	1.13%	0.96%	0.80%	1.15%
Positivity rate compared to age-weighed ONS Infection Survey	0.29	0.21	0.40	0.33	0.23	0.48

Source: Oxera and Edge Health.

Table A5.2 Comparison of Collinson pre-departure antigen and LAMP testing to London community PCR test positivity assuming 20% of symptomatic passengers opt not to fly pre-departure

Metric	Antigen			LAMP		
	Central	Lower	Upper	Central	Lower	Upper
Age-weighed ONS Infection Survey positivity rate (RT-PCR)	2.97%	2.50%	3.51%	2.60%	2.13%	3.15%
Collinson pre-departure positivity rate	0.97%	0.83%	1.13%	0.96%	0.80%	1.15%
Positivity rate compared to age-weighed ONS Infection Survey	0.33	0.24	0.45	0.37	0.26	0.54

Source: Oxera and Edge Health.

Table A5.3 Comparison of Collinson pre-departure antigen and LAMP testing to London community PCR test positivity assuming 70% of symptomatic passengers opt not to fly

Metric	Antigen			LAMP		
	Central	Lower	Upper	Central	Lower	Upper
Age-weighed ONS Infection Survey positivity rate (RT-PCR)	2.03%	1.71%	2.40%	1.78%	1.46%	2.15%
Collinson pre-departure positivity rate	0.97%	0.83%	1.13%	0.96%	0.80%	1.15%
Positivity rate compared to age-weighed ONS Infection Survey	0.48	0.34	0.66	0.54	0.37	0.79

Source: Oxera and Edge Health.

www.edgehealth.co.uk

www.oxera.com