Effectiveness of dual-testing schemes for air passengers

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Executive summary

This report is an extension of modelling that was conducted by Oxera and Edge Health in November 2020, which helped provide evidence that supported the test-to-release scheme that was subsequently implemented by the UK government in place of the mandatory 14-day quarantine requirement.[1] At the time, the UK government was mainly employing testing to reduce the volume of imported cases of COVID-19.

Since then, the UK government has introduced several additional testing and quarantine requirements. Mandatory pre-departure testing was first introduced on 15 January 2021, such that all passengers travelling to the UK must show evidence of a negative COVID-19 test, taken a maximum of three days before departure. From 15 February 2021, all arrivals to the UK have been expected to get tested on days two and eight of their ten-day quarantine. The purpose of the test administered on day two is mainly to help identify SARS-Cov-2 'variants of concern';[2] the purpose of the test on day eight is to ensure that passengers do not have COVID-19.[2] The test-to-release scheme, which allows individuals to shorten their ten-day quarantine by getting tested on day five, is still available for travellers to England.[3] In addition, arrivals from countries on the UK's travel ban list are required to complete their testing and quarantine in approved 'quarantine hotels'.[4]

These changes have been made in the context of the UK government's ongoing efforts to vaccinate the population, and concerns around the impact of variants of concern on the efficacy of the vaccination programme. At the time of writing this report, initial evidence indicates that approved vaccines (Pfizer, Moderna, AstraZeneca) are effective at preventing severe illness from COVID-19 in variants of concern identified in the UK (B.1.1.7),[5] South Africa (B.1.351),[6,7] and Brazil (P.1).[8] However, further analysis is still being undertaken.

The UK government has now re-established the Global Travel Taskforce to provide recommendations regarding how to facilitate a return to international travel as soon as possible while still managing the risk from imported cases and variants of concern.

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[1] See Oxera and Edge Health (2020), 'Modelling the effectiveness of airport testing regimes', 6 November.
[2] Instructions for travellers to England state: 'You must take a COVID-19 test on or before day 2 for variant surveillance and a test on or after day 8 to check that you do not have COVID-19'. See Department of Health and Social Care (2021), 'How to quarantine when you arrive in England', https://www.gov.uk/guidance/how-to-quarantine-when-you-arrive-in-england
[3] Ibid.
[4] See Department of Health and Social Care (2021), 'Government confirms mandatory hotel quarantine to be introduced from 15 February', press release, 5 February, https://www.gov.uk/government/news/government-confirms-mandatory-hotel-quarantine-to-be-introduced-from-15-february
[5] Mahase (2021),'COVID-19: Where are we on vaccines and variants?', https://www.bmj.com/content/372/bmj.n597
[6] A small trial in South Africa demonstrated that the AstraZeneca vaccine was less effective at preventing mild and moderate infections of the South African variant. Studies are still ongoing on the vaccine's effectiveness against severe illness. See: World Health Organization (2021), 'COVAX Statement on New Variants of SARS-CoV-2', press release, https://www.who.int/news/item/08-02-2021-covax-statement-on-new-variants-of-sars-cov-2. Other vaccines (e.g. Johnson and Johnson, Ad26COV2.S) have performed favourably in reducing severe COVID-19 in this variant, despite reductions in efficacy against symptomatic COVID-19. See Fontanet et al. (2021), 'SARS-CoV-2 variants and ending the COVID-19 pandemic', 11 February, https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(21)00370-6/fulltext#box1
[7] Moderna (2021), 'Moderna COVID-19 Vaccine Retains Neutralizing Activity Against Emerging Variants First Identified in the U.K. and the Republic of South Africa', press release, https://investors.modernatx.com/news-releases/news-release-details/moderna-covid-19-vaccine-retains-neutralizing-activity-against
[8] *The New England Journal of Medicine* (2021), 'Neutralizing Activity of BNT162b2-Elicited Serum', 8 March, https://www.nejm.org/doi/full/10.1056/NEJMc2102017

In order to determine how to safely re-start travel, it is important to consider whether, and the extent to which, quarantine and testing strategies for air passengers may be required.[9] We have therefore updated our modelling to integrate new evidence on air passenger quarantine compliance and syndromic screening to contribute to this evidence base. We also consider dual-testing regimes to compare the results to the previous single-testing regimes considered.

To capture differing risks of onward transmission for symptomatic and asymptomatic individuals, and the impact of individuals' differing quarantine compliance over time, we evaluate the efficacy of testing and quarantine schemes using the metric of *infectious days* spent in the community.

The outputs of our updated modelling suggest the following.

- A single antigen test administered on departure (or close to the time of departure) would screen 62% of potentially infectious days from entering the community. Dual-testing schemes using antigen tests 72 hours before departure and on departure would screen 67% of potentially infectious days from entering the community compared to syndromic screening alone. This suggests that a single antigen test administered close to the time of departure may be appropriate for passengers from the majority of countries. As antigen tests are relatively rapid to administer and do not require the same level of technical expertise as PCR/LAMP testing, using an antigen test on departure may also present fewer operational challenges compared to PCR/LAMP. These results differ from those previously reported by SAGE indicating that a single antigen test near the time of departure would screen only 11% of infectious travellers.[10] Differences are due, in part, to poorly performing antigen tests being used for the SAGE modelling[11] and assumptions that a high proportion of air passengers choose not to fly or are prevented from flying due to symptoms.
- Dual-testing schemes screen a higher number of infectious days and may therefore be relevant for air passengers from higher-risk countries of origin (e.g. where the prevalence of SARS-Cov-2 infections and/or variants of concern is high). For example, an antigen test administered 72 hours pre-departure combined with a LAMP or PCR test on day three would screen 85–87% of potentially infectious days from entering the community. This dual-testing scheme screens a very high proportion of infectious days, and reduces most of the risk of introducing variants of concern to the UK community, even when incorporating quarantine non-compliance, without onerous and costly hotel quarantine requirements.

To put the results of our modelling in context, even when the prevalence of COVID-19 in both the USA and the EU has been higher than that in the UK over the course of 2020–21, international air passengers would still have released fewer potentially infectious days into the community per capita compared to domestic infections.

- On 14 December 2020, when the prevalence in the USA was the highest that it has been relative to the UK, 10,000 incoming air passengers would

[9] Oxera and Edge Health (2021), 'Restarting international travel safely'.
[10] Department for Transport and Foreign, Commonwealth & Development Office (2021), 'International importation, border and travel measures', 21 January, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/961099/s1046-international-importation-border-travel-measures.pdf
[11] Oxera and Edge Health (2021), 'Assessment of the effectiveness of rapid testing for SARS-CoV-2'.

have had 77% fewer infectious days than 10,000 individuals in the UK community if a single on-departure antigen test had been administered.

- Similarly, on 6 November 2020, when the prevalence in the EU was the highest that it has been relative to the UK, 10,000 incoming air passengers would have had 71% fewer infectious days than 10,000 individuals in the UK community if a single on-departure antigen test had been administered.

Even when there is high prevalence in these locations compared to the UK, potential infectious days from air passengers coming from the USA or the EU represent a small share of the overall potential infectious days in the UK community.[12] When the population is vaccinated, this relative risk decreases further, so that testing may no longer be required for passengers from most destinations.

Therefore, in the short term, testing may be useful in both reducing imported cases and in monitoring and reducing the risk of introducing a critical mass of a variant of concern.[13] However, single-testing regimes are likely to be appropriate for the majority of countries (e.g. with low prevalence rates and high vaccination rates), with dual-testing regimes reserved for higher-risk countries (e.g. with high prevalence rates and low vaccination levels). Over time, as both the UK and others countries' populations are vaccinated, and as more evidence is available on the effect of variants of concern on the vaccination programme, it is likely that testing could be removed altogether.

[12] Based on relative prevalence values from 2020–21.
[13] It is recognised that the UK's high level of international connectivity means that preventing a variant of concern ever entering is unlikely to be feasible. See: Department for Transport and Foreign, Commonwealth & Development Office (2021), 'International importation, border and travel measures', 21 January, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/961099/s1046-international-importation-border-travel-measures.pdf

1 Introduction

Oxera and Edge Health have been asked to consider the effectiveness of dual-testing schemes for air passengers.

In this report, we model the effectiveness of dual-testing schemes for air passengers by comparing infection risk from air passengers to: a base case with syndromic screening alone; single-testing schemes; and infection risk in the domestic population. We assess three different types of testing technologies: PCR, LAMP, and antigen.

This report is an extension of modelling that was conducted by Oxera and Edge Health in November 2020,[14] which helped provide evidence that supported the efficacy of schemes with shorter quarantine periods and testing compared to a 14-day quarantine alone. Since November 2020, we have also updated our modelling for another report, Oxera and Edge Health (2021), 'Assessment of the effectiveness of rapid testing for SARS-CoV-2', in which we focused on the effectiveness of single-testing schemes using antigen technology. These results are used for comparison to the dual-testing schemes examined in this report.

The rest of the report is structured as follows:

- section 2 sets out our methodology, including the updates we have made since the November 2020 report;
- section 3 presents the results of dual-testing schemes, comparing them to single-testing scheme results and to domestic prevalence;
- section 4 concludes.

The appendices contain further detail on the analysis.

[14] See Oxera and Edge Health (2020), 'Modelling the effectiveness of airport testing regimes', 6 November.

2 Methodology

To undertake our analysis, we have updated our previous modelling, which was based on work published by the London School of Hygiene & Tropical Medicine (LSHTM) in July 2020,[15] to include dual-testing and antigen testing. We have also updated our model based on the most recent evidence from the Office for National Statistics (ONS) on post-arrival quarantine compliance (hereafter 'the ONS Survey'), and from the Centers for Disease Control and Prevention (CDC) on syndromic screening.[16]

To evaluate the effectiveness of dual-testing schemes for air passengers, we compare infection risk from air passengers to: a base case with syndromic screening alone; single-testing schemes; and infection risk in the domestic population.[17]

The remainder of this section is structured as follows:

- section 2.1 provides an overview of the modelling framework;
- section 2.2 describes how we measure infection risk;
- section 2.3 outlines the dual-testing strategies we have modelled;
- section 2.4 summarises key updates for air passenger infection risk modelling;
- section 2.5 summarises key updates for domestic infection risk modelling.

Details on all modelling parameters and assumptions are outlined in Appendices A1 and A2.

2.1 Modelling framework

In this report, we evaluate the effectiveness of different dual-testing schemes and quarantine policies at preventing individuals with SARS-Cov-2 infections from entering the community and spreading the infection in the UK population. Preventing individuals with SARS-Cov-2 from entering the community also reduces the risk of introducing a critical mass of variants of concern into the community.

[15] See Oxera and Edge Health (2020), 'Modelling the effectiveness of airport testing regimes', 6 November. For LSHTM's work see: Clifford et al. (2020), 'Strategies to reduce the risk of SARS-CoV-2 re-introduction from international travellers', 25 July.

[16] This report contains a similar update in methodology as the antigen testing report, where we focused on single-testing schemes. See Oxera and Edge Health (2021), 'Assessment of the effectiveness of rapid testing for SARS-CoV-2'. For the ONS Survey, see: Office for National Statistics (2020), 'Non-exempt international arrivals self-isolation behavioural survey pilot, UK, 30 September to 8 October 2020', 1 December, https://www.ons.gov.uk/peoplepopulationandcommunity/healthandsocialcare/conditionsanddiseases/adhocs/12575nonexemptinternationalarrivalsselfisolationbehaviouralsurveypilotuk30septemberto8october2020. Syndromic screening is defined as passengers either self-screening or being screened at the airport because of symptoms consistent with COVID-19. CDC evidence suggests that airport screening by others may be a relatively ineffective mechanism of identifying and preventing imported cases. For the CDC's work, see: Centers for Disease Control and Prevention (2020), 'Risk Assessment and Management of COVID-19 Among Travelers Arriving at Designated U.S. Airports, January 17–September 13, 2020', 13 November, https://www.cdc.gov/mmwr/volumes/69/wr/mm6945a4.htm

[17] To compare infection risk from air passengers to that from the domestic population, we adapt the air passenger model to the domestic population (see section 2.5 for further details).

We use Monte Carlo methods to simulate:

- the proportion of passengers intending to travel who are expected to be infected, based on infection prevalence at the departure location;[18]
- the proportion of inbound infected passengers who develop symptoms or are infected but asymptomatic;
- for infected passengers, how their infection evolves. For symptomatic individuals, this includes simulating the time from initial infection to symptoms onset, the duration of symptoms, and the time from initial infection to infectiousness and infectiousness duration. For asymptomatic individuals, this includes simulating the time from initial infection to infectiousness and infectiousness duration;
- the time between initial infection and flight departure;
- compliance with quarantine under three scenarios: i) symptom compliance, should an individual become symptomatic in their origin country or once they have arrived at their destination; ii) quarantine compliance, government requirements to quarantine post-arrival while waiting to be tested; iii) quarantine compliance, should an individual receive a positive test indicating a SARS-Cov-2 infection. (These updated parameters are outlined in section 2.4.)

These parameters are combined to create multiple potential passenger journeys. For example, some of the simulated passengers may become infected but no longer be infectious by the time that they are due to fly. Other individuals may become infected and develop COVID-19 symptoms by the time that they fly, at which point they will either choose not to fly or decide to travel despite their symptoms.[19] Other individuals may become infected in the days just prior to flying, at which point they are not likely to present COVID-19 symptoms. They are also unlikely to yet be infectious. Depending on the post-arrival quarantine and passenger compliance scenarios modelled, these individuals may spend all of their infectious days in the community, be screened through testing, or choose to self-quarantine if they develop symptoms.

While not explicitly modelled, we discuss the impact of testing schemes on reducing the risk of introducing a critical mass of a variant of concern (see section 4).

2.2 Measuring infection risk

To measure the efficacy of the modelled testing strategies, we use the metric of infectious days. This metric allows for a more comprehensive understanding of infection risk compared to measuring infectious individuals screened.[20] It includes:

- **differing infectiousness levels for symptomatic and asymptomatic passengers.** Depending on whether an individual is symptomatic or

[18] Note that this methodology does not account for differing age and comorbidity structures across countries when estimating actual infection prevalence from reported cases.
[19] Syndromic screening is defined as the combination of individuals being prevented from boarding flights due to presenting symptoms consistent with COVID-19 at the airport or opting not to fly for the same reason.
[20] A few studies have also attempted to scale infectious days by how infectious each day might be. For example, viral load and infectiousness tend to peak around the beginning of symptoms (for symptomatic individuals). See, for example, Clifford et al. (2020), 'Quarantine and testing strategies in contact tracing for SARS-CoV-2: a modelling study', 23 October, https://www.medrxiv.org/content/10.1101/2020.08.21.20177808v3

asymptomatic, they will have different durations of infectiousness. We model the median number of infectious days for symptomatic individuals as 7.1 days and for asymptomatic individuals as 5.3 days (see Appendices A1 and A2);

- **differing quarantine compliance states over time.** This metric provides an indication of the effectiveness of different testing/quarantine schemes at reducing infection spread once quarantine compliance is introduced, as it accounts for changing compliance levels upon receipt of a positive test or upon developing symptoms.

When calculating the relative efficacy of testing schemes, we present infectious days screened relative to a scenario with syndromic screening alone. When comparing infection risk of air passengers to the domestic population, we present infectious days from air passengers compared to infectious days already in the community.

2.3 Testing strategies modelled

In dual-testing schemes, the first test is always conducted 72 hours before departure, with the second test conducted on departure or after arrival. Our modelling includes a variety of testing scheme options, based on different combinations of pre-arrival quarantine requirements, testing technology used, and timing of the administration of the second test. These are outlined in Table 2.1.

Table 2.1 Modelled dual-testing schemes

Test 1 timing	Test 1 type	Test 2 timing	Test 2 type
Test 72 hours pre-departure, with self-isolation pre-departure	RT-PCR/RT-LAMP/ antigen	Ten-day isolation (no second test)	N/A
		Test on departure	RT-LAMP/antigen[1]
		Test after 0–5 days	RT-PCR/ RT-LAMP/antigen
Test 72 hours pre-departure, without self-isolation pre-departure	RT-PCR/RT-LAMP/ antigen	Ten-day isolation (no second test)	N/A
		Test on departure	RT-LAMP/antigen[1]
		Test after 0–5 days	RT-PCR/ RT-LAMP/antigen

Note [1] RT-PCR is not considered for on-departure testing because the test turnaround time is generally too long for it to be used in this setting.

Source: Oxera and Edge Health.

Modelled scenarios include the testing and quarantine schemes that the UK government had in place between mid-January and mid-February 2021: a test 72 hours pre-departure and a test on day five (test-to-release scheme); or a test 72 hours pre-departure and a quarantine period of ten days.

We compare the dual-testing modelling results to single-testing modelling results using the same input assumptions and testing technologies.[21] The single-testing modelling analysis includes the scenarios outlined in Table 2.2.

[21] Single-testing modelling results based on work conducted for IATA.

Table 2.2 Modelled single-testing schemes

Testing scheme	Timing of test	Pre-departure quarantine requirement	Testing technology
Baseline	None	None	None
Ten-day quarantine[1]	None	None	None
Pre-departure	Three days pre-departure	Quarantine for 72 hours pre-departure; or no quarantine	RT-PCR/RT-LAMP/ antigen
On departure[2]	At airport, on departure	None	RT-LAMP/antigen
On arrival	At airport, on arrival	None	RT-PCR/RT-LAMP/ antigen
Post-arrival	One to five days post-arrival	None	RT-PCR/RT-LAMP/ antigen

Note: [1] We consider a ten-day quarantine alone, not a ten-day quarantine in combination with a pre-departure test (as has been recently implemented in the UK), as this report does not focus on the combination of pre-departure testing with other quarantine and testing measures. [2] RT-PCR is not considered for on-departure testing because the test turnaround time is generally too long for it to be used in this setting.

Source: Oxera and Edge Health (2021), 'Assessment of the effectiveness of rapid testing for SARS-CoV-2'.

2.4 Integrating new evidence into air passenger modelling

The key areas where we have updated assumptions for this analysis are as follows.[22]

- **Antigen testing:** We have included antigen testing in addition to presenting the results based on molecular testing (PCR/LAMP). In our work on antigen testing,[23] we have found that antigen tests have a wider range of sensitivity compared to molecular testing. This variance is affected by several factors, most notably the brand of test, the viral loads of the population being tested, and testing conditions. Antigen tests tend to have higher sensitivity in the first week following symptom onset (when individuals have higher viral loads)[24] and sensitivity tends to drop off more quickly than in molecular tests (e.g. PCR/LAMP). Pre-symptomatic and asymptomatic test sensitivity also tends to be lower for most brands of antigen tests, although a few brands have reported better performance with these groups.
- **Quarantine compliance:** New evidence from the ONS Survey suggests that quarantine compliance in the UK may be higher than suggested by previous international survey evidence.[25] However, this ONS data also

[22] As also outlined in: Oxera and Edge Health (2021) 'Assessment of the effectiveness of rapid testing for SARS-CoV-2'.
[23] Ibid.
[24] Mina et al. (2020) 'Rethinking Covid-19 Test Sensitivity — A Strategy for Containment', 26 Nov. https://www.nejm.org/doi/pdf/10.1056/NEJMp2025631?articleTools=true
[25] As compliance is self-reported, individuals may report higher quarantine compliance compared to their actual behaviour. For the ONS Survey, see: Office for National Statistics (2020), 'Non-exempt international arrivals self-isolation behavioural survey pilot, UK, 30 September to 8 October 2020', 1 December, https://www.ons.gov.uk/peoplepopulationandcommunity/healthandsocialcare/conditionsanddiseases/adhocs/12575nonexemptinternationalarrivalsselfisolationbehavioursurveypilotuk30septemberto8october2020. For previous international survey evidence, see: Steens, A., Freiesleben de Blasio, B., Veneti, L., Gimma, A., Edmunds, J.W., Van Zandvoort, K., Jarvis, C.I., Forland, F. and Robberstad, (2020), 'Poor self-reported adherence to COVID-19-related quarantine/isolation requests, Norway, April to July 2020', Euro Surveill. 2020;25(37):pii=2001607, https://doi.org/10.2807/1560-7917.ES.2020.25.37.2001607

shows that compliance decreases over the quarantine period. There are three levels of compliance included in the ONS Survey: i) individuals fully complying with the guidance; ii) an intermediate group, which could be regarded as compliant or non-compliant depending on the context, for example leaving home to get basic necessities; and iii) individuals not complying at all with guidance. The results of the ONS Survey data are included in Table 2.3.

Table 2.3 Self-reported quarantine compliance over time in the UK air passenger population

Days in quarantine	Those who were definitely compliant with government guidelines	Those who may have been compliant with government guidelines	Those who were definitely not compliant with government guidelines
5	72%	20%	8%
8	71%	20%	9%
13	58%	24%	18%

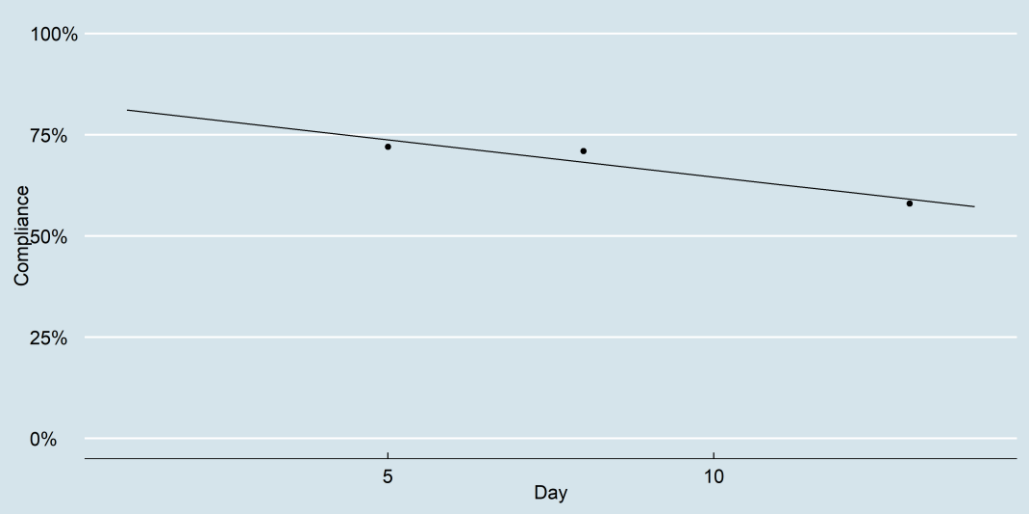
Source: Oxera and Edge Health, based on the ONS Survey.

The ONS Survey also includes information on the number of times that those in quarantine left their accommodation while quarantining. Most passengers reported having left their place of quarantine only a handful of times. Further work could be undertaken to consider the level of risk from these individuals, given the types of activities that they engaged in and the number of times they left their accommodation.

However, for the purposes of this analysis, we assume that compliance levels are equivalent to the individuals who can definitely be regarded as compliant. While individuals in the second group, who are non-compliant for reasons such as leaving the house to buy necessities, may be engaging in lower-risk activities than those in group three, who are definitely non-compliant, we account for the potential risk associated with both groups.

To estimate quarantine compliance on each day of quarantine from the available compliance data, we use a linear regression (see Figure 2.1).

Figure 2.1 Relationship between days in quarantine and compliance



Note: Oxera and Edge Health based on ONS data.

- **Syndromic screening:** Syndromic screening refers to the combination of: i) passengers self-screening by choosing not to fly when they develop symptoms; and ii) passengers being prevented from flying at the airport because of their symptoms. The relative efficacy of each testing scheme is benchmarked against a base-case scenario with syndromic screening alone. Earlier modelling from LSHTM assumed that 70% of symptomatic passengers at the time of departure would choose not to fly or be prevented from flying.[26] Since this modelling was undertaken, real-world studies on symptom screening at airports (i.e. passengers being screened for symptoms by airport or government staff) have suggested that it is an ineffective measure to identify test-confirmed positive infections.[27] Thus, syndromic screening is mainly driven by passengers choosing not to fly when they develop symptoms. Therefore, we set syndromic screening efficacy to be the same as compliance with quarantine upon developing symptoms consistent with COVID-19 from survey evidence (see Table 2.4 below), although we also present a sensitivity analysis.

Table 2.4 below provides a summary of updated parameters and sources. Appendix A1 provides the full list of modelling assumptions.

[26] Clifford et al. (2020), 'Strategies to reduce the risk of SARS-CoV-2 re-introduction from international travellers', 25 July. 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

[27] See Centers for Disease Control and Prevention (2020), 'Risk Assessment and Management of COVID-19 Among Travelers Arriving at Designated U.S. Airports, January 17–September 13, 2020', 13 November, https://www.cdc.gov/mmwr/volumes/69/wr/mm6945a4.htm

Table 2.4 Updated model parameters, including descriptions and sources: air passenger population

Model input	Description
Proportion of infected passengers (prevalence estimates)	Based on prevalence in the passenger's departure region (either the USA or the EU). Methodology from Russell et al. (2020) used to estimate under-ascertainment of SARS-CoV-2 cases in Europe and the USA. Figures updated to reflect the difference in prevalence between the departure and arrival destinations when it was at its lowest, highest and median values over the course of 2020. Underlying age/comorbidity structures and passenger demographics not considered[28]
Number of people intending to fly	Average monthly historical volumes from 2019 scaled to reflect 2020 volumes.[29] To reflect potential future airline volume increases as vaccinations are rolled out and protection to the domestic population increases, we present potential airline volumes between 10% and 30% higher than they were in 2020.
Antigen test sensitivity	Antigen test sensitivity can vary significantly depending on the brand of test used, the population being tested and the time window post-infection in which the test is administered. The test we use in our analysis is referred to as the 'FDA-approved antigen test' throughout this report. It has the following reported sensitivities compared to PCR: • pre-symptomatic: 80% • 0–7 days post-symptom onset: 95%[30] • 8+ days post-symptom onset: 80% • asymptomatic: 80% As a sensitivity analysis, we also include a WHO-approved brand (referred to as the 'WHO-approved antigen test' throughout this report). We scale PCR sensitivity by the following factors for this brand: • pre-symptomatic: 66%[31] • 0–7 days post-symptom onset: 86%[32] • 8+ days post-symptom onset: 54% • asymptomatic: 66%
Air passenger quarantine compliance rate	We extrapolate data on air passenger quarantine compliance over time available from the ONS Survey and apply cumulative compliance values to quarantines of different durations. The survey reports: 72% of respondents definitely complying with quarantine by day 5, 71% of respondents definitely complying with quarantine by day 8, and 58% of respondents complying by day 13.[33] We apply these quarantine compliance rates to both symptomatic and asymptomatic passengers.

[28] Russell, T.W., Golding, N., Hellewell, J., Abbott, S., Wright, L., Pearson, C.A.B., van Zandvoort, K., Jarvis, C.I., Gibbs, H., Yang, L., Eggo, R.M., Edmunds, J.W. and Kucharski, A.J. (2020), 'Reconstructing the early global dynamics of under-ascertained COVID-19 cases and infections', medRxiv 2020.07.07.20148460, https://doi.org/10.1101/2020.07.07.20148460
[29] Airport data 2020 05 from UK Civil Aviation Authority website, https://www.caa.co.uk/Data-and-analysis/UK-aviation-market/Airports/Datasets/UK-Airport-data/Airport-data-2019/ [cited 2020 4 July].
[30] Pilarowski et al. (2020), 'Field performance and public health response using the BinaxNOWTM Rapid SARS-CoV-2 antigen detection assay during community-based testing'.
[31] See: https://www.globalpointofcare.abbott/en/product-details/panbio-covid-19-ag-antigen-test.html
[32] Linares et al. (2020), 'Panbio antigen rapid test is reliable to diagnose SARS-CoV-2 infection in the first 7 days after the onset of symptoms', 4 December, https://www.sciencedirect.com/science/article/abs/pii/S1386653220304017?via%3Dihub
[33] Office for National Statistics (2020), 'Non-exempt international arrivals self-isolation behavioural survey pilot, UK, 30 September to 8 October 2020', 1 December, https://www.ons.gov.uk/peoplepopulationandcommunity/healthandsocialcare/conditionsanddiseases/adhocs/12575nonexemptinternationalarrivalsselfisolationbehaviouralsurveypilotuk30septemberto8october2020

Model input	Description
Symptomatic quarantine compliance rate	In addition to being required to quarantine due to travel, in most jurisdictions individuals are also asked to quarantine if they develop symptoms consistent with COVID-19. Therefore, we include quarantining due to symptoms in our model as well. We set this at 18.2% for symptomatic individuals.[34] This is based on survey evidence in the UK population from King's College London.[35] This is applied to individuals both pre- and post-arrival at their destination.
Syndromic screening rate	18.2% of passengers symptomatic at the time of their flight decide not to travel, consistent with survey evidence from King's College London on symptomatic quarantine compliance.[36] As a sensitivity analysis a syndromic screening of 70% is included, reflecting early modelling on pre-departure screening.[37]

Source: Oxera and Edge Health.

2.5 Integrating new evidence into domestic infection modelling

To be able to compare the risk from international air passengers to domestic infection risk,[38] we have adapted the air passenger modelling framework to estimate infectious days potentially released into the community by the UK population rather than air passengers.

We have done this by adding UK prevalence assumptions to the original model, and by removing components of the modelling framework that pertain only to air passengers (e.g. the simulated flight departure time and the travel quarantine requirements).

In the updated modelling framework, we assume that people in the UK quarantine for two reasons: [39] after developing symptoms consistent with COVID-19, or after receiving a positive test that they chose to take after they developed symptoms. The probability of a person seeking a test when symptomatic is set to 10.9% as measured by the Survey of Adherence to Interventions and Responses.[40]

[34] Quilty, B.J., Clifford, S., Flasche, S., Eggo, R.M., CMMID nCoV working group (2020), 'Effectiveness of airport screening at detecting travellers infected with novel coronavirus (2019-nCoV)', Euro Surveill, Feb;25(5), http://dx.doi.org/10.2807/1560-7917.ES.2020.25.5.2000080
[35] This has been updated from previously used international evidence based on the Norwegian population (based on a mix of individuals returning from international travel or being required to quarantine from contact tracing).
[36] Ibid.
[37] 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
[38] In addition to risk from air passengers in a base case with syndromic screening alone.
[39] Due in part to case under-ascertainment, the UK's test-and-trace system is contacting a relatively low proportion of cases as a share of the UK's overall caseload; for this reason we do not include this in our modelling framework. While the test-and-trace contact rate is improving, we expect the impact of test-and-trace on reducing infectious days spent in the community to be relatively low as long as there is relatively significant case under-ascertainment.
[40] 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

Table 2.5 Updated model parameters, including descriptions and sources

Model input	Description
Proportion of infected population (prevalence estimates)	In the UK, the ONS publishes weekly reports of the percentage of people in the community testing positive for SARS-CoV-2.[41] These estimates are at the national level, which we use to calculate the UK community prevalence
Compliance with getting tested, if symptomatic	10.9%[42]
Symptomatic quarantine compliance rate	18.2%[43] for symptomatic individuals

Source: Oxera and Edge Health.

[41] ONS Infection Survey data available from Office for National Statistics (2021), 'Coronavirus (COVID-19) Infection Survey, UK Statistical bulletins', https://www.ons.gov.uk/peoplepopulationandcommunity/healthandsocialcare/conditionsanddiseases/bulletins/coronaviruscovid19infectionsurveypilot/previousReleases

[42] 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

[43] Steens, A., Freiesleben de Blasio, B., Veneti, L., Gimma, A., Edmunds, J.W., Van Zandvoort, K., Jarvis, C.I., Forland, F. and Robberstad, (2020), 'Poor self-reported adherence to COVID-19-related quarantine/isolation requests, Norway, April to July 2020', Euro Surveill. 2020;25(37):pii=2001607, https://doi.org/10.2807/1560-7917.ES.2020.25.37.2001607

3 Results

As outlined in the previous section, we model each of the dual-testing schemes with and without a pre-departure quarantine requirement. If passengers coming to the UK are required to quarantine pre-departure,[44] more infectious days will be prevented from entering the UK. However, as pre-departure quarantine compliance may be difficult for the UK government to monitor or enforce, we focus on dual-testing schemes without a pre-departure quarantine in this report. The results with pre-departure quarantine requirements are included in Appendix A1.

The rest of this section is structured as follows:

- section 3.1 presents the relative efficacy of dual-testing schemes compared to the base case with syndromic screening alone, and to single-testing schemes;
- section 3.2 compares infectious days from air passengers to infectious days from the domestic population;
- section 3.3 presents sensitivity analysis.

3.1 Relative efficacy of testing schemes

3.1.1 Dual-testing schemes

The results for dual-testing schemes are presented in Table 3.1 below. This table shows the percentage of infectious days screened from the community compared to the base case, for different combinations of test types and timings While the timing of the second test varies, the first test is always administered 72 hours before departure. In addition to the dual-testing schemes, a single-testing scheme with a test administered 72 hours before departure and a subsequent ten-day quarantine period is presented.

There are several conclusions that are apparent from the data presented in Table 3.1.

- For the first test, the type of test administered (PCR, LAMP or antigen), appears to have a minimal impact on the overall efficacy of the testing scheme. For example, between 82% and 83% of infectious days are screened with a test 72 hours before departure and a PCR test one day after arrival, regardless of whether the pre-departure test is PCR, LAMP or antigen. This result holds across the different test timing scenarios for the second test.
- For the second test, the relative benefit of the type of test administered (PCR, LAMP or antigen) depends on the timing of the second test. PCR screens 5–6% more infectious days compared to LAMP and antigen tests when administered on arrival (e.g. 77% compared to 72% and 71%). This is mainly because of the additional quarantine requirement associated with the longer turnaround time for the results of a PCR test. As the post-arrival quarantine period increases, differences in infectious days screened between PCR and LAMP/antigen testing decreases such that by day five there is no difference.

[44] And have pre-departure quarantine compliance levels the same as those reported by air passengers after arriving in the UK.

- While second tests administered with a three-day post-arrival quarantine screen the largest proportion of infectious days, dual-testing schemes with shorter post-arrival quarantine periods also screen a high proportion of infectious days. For example, two antigen tests—one administered 72 hours before departure and one administered on arrival—screen 71% of infectious days. An antigen test administered 72 hours pre-departure combined with a ten-day post-arrival quarantine screens 74% of infectious days compared to the base case.
- Second tests administered on departure screen a similar proportion of infectious days to those administered on arrival. For longer flight times (e.g. flights between the USA and the UK), some individuals may become detectable while travelling leading to slightly higher results for on-arrival compared to on-departure tests.

Table 3.1 Modelling results for dual-testing schemes

		Second test type			
First test type	**Second test timing***	**PCR**	**LAMP**	**FDA-antigen**	**No second test**
PCR	D-72 only	-	-	-	45% (23–69%)
	D=0	-	71% (49–89%)	69% (48–88%)	-
	A=0	77% (58–94%)	72% (52–91%)	71% (51–90%)	-
	1	83% (67–96%)	80% (61–96%)	78% (59–94%)	-
	2	86% (71–97%)	84% (68–96%)	83% (66–97%)	-
	3	88% (75–98%)	86% (71–97%)	85% (69–96%)	-
	4	88% (74–100%)	86% (74–96%)	85% (70–95%)	-
	5	86% (74–98%)	86% (73–96%)	85% (72–95%)	-
	Ten-day quarantine	-	-	-	75% (57–92%)
LAMP	D-72 only	-	-	-	41% (18–63%)
	D=0	-	69% (47–88%)	67% (47–87%)	-
	A=0	77% (58–93%)	72% (52–90%)	71% (50–90%)	-
	1	82% (66–97%)	79% (60–96%)	77% (60–95%)	-
	2	86% (70–97%)	83% (66–95%)	81% (65–95%)	-
	3	87% (73–97%)	85% (70–97%)	84% (69–95%)	-
	4	87% (72–96%)	85% (72–97%)	84% (71–97%)	-
	5	85% (70–96%)	85% (70–95%)	84% (68–95%)	-
	Ten-day quarantine	-	-	-	75% (54–92%)

		Second test type			
First test type	**Second test timing***	**PCR**	**LAMP**	**FDA-antigen**	**No second test**
FDA-antigen	D-72 only	-	-	-	38% (17–59%)
	D=0	-	68% (47–89%)	67% (46–87%)	-
	A=0	76% (58–93%)	72% (51–90%)	71% (49–90%)	-
	1	83% (65–95%)	78% (61–97%)	77% (60–95%)	-
	2	85% (69–96%)	83% (67–95%)	81% (65–95%)	-
	3	87% (73–97%)	85% (70–96%)	83% (68–96%)	-
	4	86% (72–96%)	84% (72–96%)	84% (69–94%)	-
	5	84% (69–96%)	85% (68–95%)	83% (67–95%)	-
	Ten-day quarantine	-	-	-	74% (54–90%)

Note: 90% confidence intervals in brackets. * Refers to second test timing with the exception of the D-72 only or D-72 with a ten-day quarantine scenario.

Source: Oxera and Edge Health.

3.1.2 Single-testing schemes

We also evaluate the marginal benefit of dual-testing schemes compared to single-testing schemes. Table 3.2 presents the percentage of infectious days screened compared to the base case by test type and timing of administration for single-testing schemes. Results for the single-testing schemes are compared to a ten-day quarantine alone, without a pre-departure test.

The patterns observed across single-testing schemes are comparable to those observed in dual-testing. PCR, LAMP and antigen technology screen comparable proportions of infectious days. As the length of the post-arrival quarantine period increases, differences in performance between test types narrow.

A single on-departure antigen test screens 62% of infectious days—equivalent to a ten-day quarantine without a pre-departure test.

Table 3.2 Single-testing scheme results

	PCR	LAMP	FDA-approved antigen test	No test requirement
D-72	45% (23–69%)	41% (18–63%)	38% (17–59%)	-
D=0	-	65% (43–83%)	62% (39–86%)	-
A=0	72% (53–89%)	65% (43–86%)	63% (40–85%)	-
1	76% (59–89%)	71% (52–88%)	69% (48–88%)	-
2	78% (63–91%)	75% (60–89%)	73% (55–88%)	-
3	79% (63–90%)	76% (61–88%)	75% (57–88%)	-
4	77% (60–90%)	76% (60–89%)	74% (58–88%)	-
5	74% (57–88%)	75% (59–87%)	74% (57–88%)	-
10	-	-	-	62% (41–81%)

Note: 90% confidence intervals in brackets.

Source: Oxera and Edge Health (2021), 'Assessment of the effectiveness of rapid testing for SARS-CoV-2'.

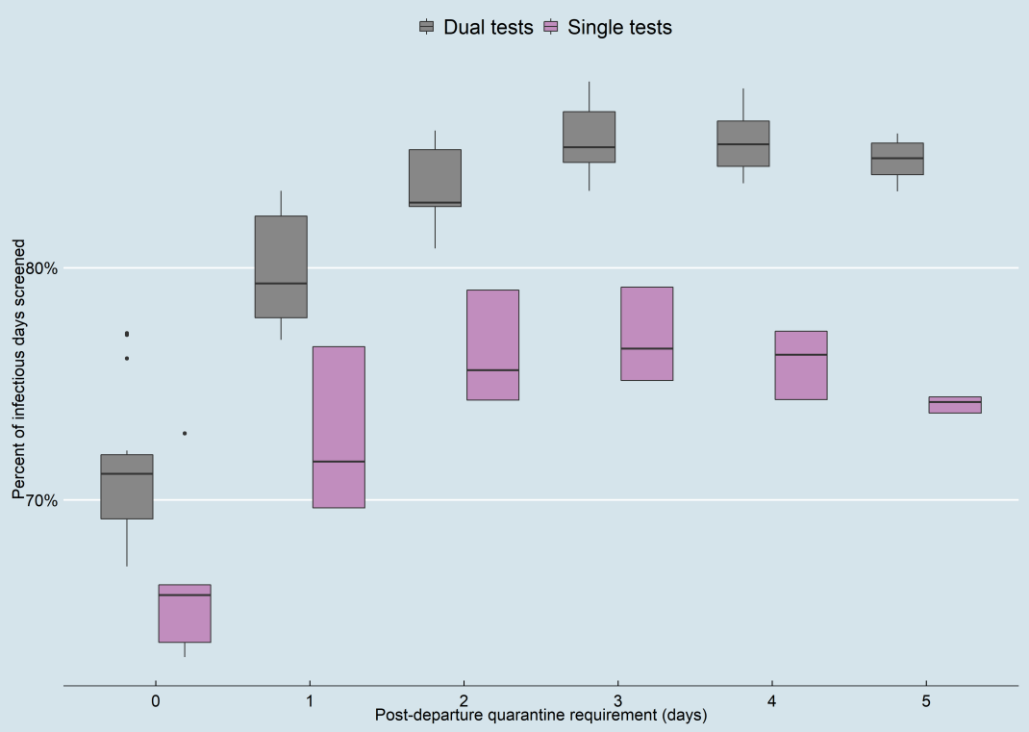
3.1.3 Comparison of dual- and single-testing schemes

Depending on the point in time at which the second test is administered, dual-testing schemes screen approximately 5–9% additional infectious days compared to single-testing schemes (while holding the type of test constant).

The marginal benefit of dual-testing is slightly lower for schemes that do not include post-arrival quarantine periods (see Figure 3.1 below). For example, while a single antigen test administered on departure screens 62% of infectious days, two antigen tests—one administered 72 hours pre-departure and one administered on departure—screen 67% of infectious days. Considering the additional costs associated with dual-testing, a single test

administered on departure (or close to the time of departure) is a relatively effective option.

Figure 3.1 Comparison of dual-testing and single-testing schemes



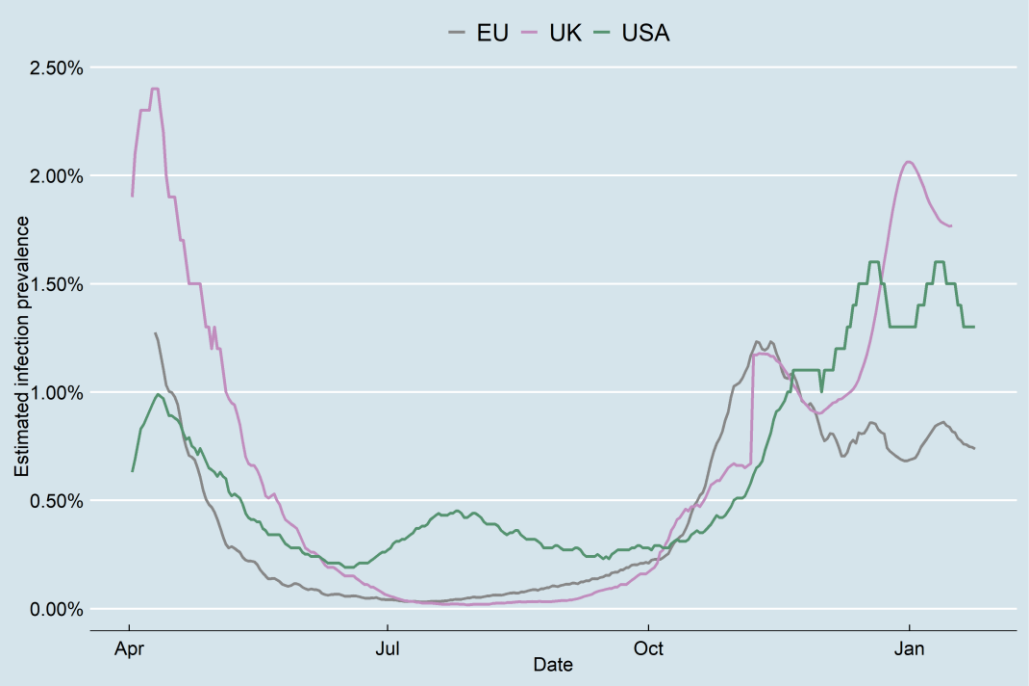
Source: Oxera and Edge Health.

3.2 Performance of dual-testing schemes relative to domestic infectious days

Since the beginning of the pandemic, SARS-Cov-2 infection prevalence has varied significantly by country and over time. The relative risk of infected air passengers to the domestic population has therefore also varied.

To illustrate changing relative risk levels depending on differences in prevalence rates in origin and destination locations, we use estimated infection prevalence in the UK, the EU and the USA over the course of 2020–21. We then identify the dates at which prevalence rates in the USA or the EU were lowest compared to the UK, highest compared to the UK, and the median difference. These points represent reasonable scenarios for differences in levels of SARS-Cov-2 over time.

Figure 3.2 Relative estimated infection prevalence between origins and destinations



Source: Oxera and Edge Health, based on modelling from Russell et al. (2020) and estimates from the ONS Infection Survey (for UK prevalence past November 2020). Russell, T.W., Golding, N., Hellewell, J., Abbott, S., Wright, L., Pearson, C.A.B., van Zandvoort, K., Jarvis, C.I., Gibbs, H., Yang, L., Eggo, R.M., Edmunds, J.W. and Kucharski, A.J. (2020), 'Reconstructing the early global dynamics of under-ascertained COVID-19 cases and infections', medRxiv 2020.07.07.20148460, https://doi.org/10.1101/2020.07.07.20148460. Office for National Statistics (2021), 'Coronavirus (COVID-19) Infection Survey, UK Statistical bulletins', https://www.ons.gov.uk/peoplepopulationandcommunity/healthandsocialcare/conditionsanddiseases/bulletins/coronaviruscovid19infectionsurveypilot/previousReleases

For both the USA and the EU, the relative proportion of infectious days from air passengers is less than that of the domestic population, across differences in prevalence levels (see Table 3.3). For example, even on 14 December 2020, when the estimated prevalence in the USA was the highest compared to that of the UK, 10,000 incoming air passengers would still spend fewer infectious days in the community compared to 10,000 people in the domestic population when antigen testing was implemented at departure. The combination of passengers spending some of their infectious days in the USA instead of the UK, air passengers choosing not to travel due to symptoms, and passengers being detected via testing means that even though prevalence in the USA was higher than in the UK, air passengers would spend 77% fewer days in the community compared to an equivalent number of individuals from the domestic population. This suggests that the risk from imported infectious days is significantly lower than that posed by domestic community transmission, and that testing can be used to facilitate travel from countries with higher prevalence rates than the UK.

Table 3.3 Proportion of infectious days from air passengers from the USA and the EU as a share of infectious days from the UK population, per 10,000 population

	USA				EU			
	Date	Antigen D=0	Antigen D-72 + D=0	Antigen / PCR D+72 + A+3	Date	Antigen D=0	Antigen D-72 + D=0	Antigen / PCR D+72 + A+3
Prevalence highest compared to the UK	14/12/20	23%	20%	8%	06/11/20	29%	25%	10%
Median prevalence difference	05/10/20	17%	15%	6%	29/06/20	9%	8%	3%
Prevalence lowest compared to the UK	05/10/20	6%	5%	2%	31/12/20	5%	5%	2%

Source: Oxera and Edge Health. Infectious days are initially calculated per 10,000 population of either air passengers or for the domestic population.

When we also consider the share of air passengers as a fraction of the total domestic population, the small overall contribution of infectious days from air passengers is evident. This remains the case even when accounting for a US prevalence higher than that of the UK (as at 14 December 2020). For example, given average passenger volumes between the USA and the UK of 52,000[45] in 2020 (equivalent to approximately 26,000 monthly inbound passengers), air passengers not screened by a single antigen test on departure would account for 0.009% of total infectious days in the UK. Even if air passenger volumes from the USA recovered to 30% of 2019 volumes (approximately 277,283 monthly inbound passengers), air passenger infectious days would be 0.090% of total infectious days in the community.

In effect, even in the absence of testing, potential infectious days from air passengers coming from the USA or the EU represent a small share of the overall potential infectious days in the UK community.[46]

As the UK continues to vaccinate its population, the risk of COVID-19 to the domestic population will continue to decrease. The introduction of potentially infectious days into the domestic population will present a lower risk if the domestic population is unlikely to develop severe disease. If individuals travelling to the UK are also vaccinated, the risk will be further reduced. As a result, testing may not be required for travel for certain individuals or for individuals from certain countries. For passengers coming from countries with low vaccination levels and medium or high prevalence rates, testing will reduce the risk of importing infections and variants of concern. While initial results on the efficacy[47] of vaccines against variants of concern are encouraging, testing can be used to monitor variants of concern in the short term, as more research becomes available.

[45] Airport data 2020 05 from UK Civil Aviation Authority website, https://www.caa.co.uk/Data-and-analysis/UK-aviation-market/Airports/Datasets/UK-Airport-data/Airport-data-2019/ [cited 2020 4 July].
[46] Based on relative prevalence values from 2020–21.
[47] Meaning the efficacy at protecting against severe illness from COVID-19.

3.3 Sensitivity analyses

3.3.1 Relative performance of dual-testing schemes with different syndromic screening assumptions

The relative performance of each testing scenario presented in section 3.1.1 is benchmarked against a scenario with syndromic screening alone.

While early modelling evidence suggested that 70% of air passengers who were symptomatic at the time of departure would either be prevented from flying or choose not to travel,[48] more recent evidence suggests that this may be an overestimate.[49] Therefore, as outlined in section 2.4, we assume that 18.2% of passengers who develop symptoms choose not to travel.[50]

Our sensitivity analysis shows that the median relative effectiveness of all modelled dual-testing schemes is approximately 8% lower when we assume that 70% (rather than 18.2%) of symptomatic air passengers choose not to travel. Assumptions on syndromic screening do not, however, affect the absolute number of infectious days screened pre-departure.

This shows that irrespective of air passenger behaviour pre-departure, testing schemes are an effective way of screening infectious days from entering the community.

3.3.2 Relative performance of dual-testing schemes with different antigen test sensitivity assumptions

In our review of antigen testing technology,[51] we found that antigen tests had a wide range of sensitivities. Antigen test sensitivity can vary depending on a number of factors, including the brand of test[52] and the population[53] being tested. To demonstrate potential variation in the relative performance of dual-testing schemes where an antigen test is used at least once, we have modelled results for a WHO-approved test in addition to the FDA-approved test from our central modelling scenario (see Figure 3.3).

The WHO-approved test has a slightly lower sensitivity for pre-symptomatic and asymptomatic individuals. Despite its lower sensitivity for these groups, it still performs similarly to the FDA-approved test.

[48] 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

[49] This was used in the LSHTM paper 'given the awareness of the pandemic and guidance issued on travelling while ill', and in our previous work. However, real-world studies on airport symptom screening (i.e. passengers being screened for symptoms by airport or government staff) have since suggested that airport screening is an ineffective measure to identify test-confirmed positive infections. Furthermore, evidence outlined in section 2 suggests that symptomatic quarantine compliance may also be relatively low.

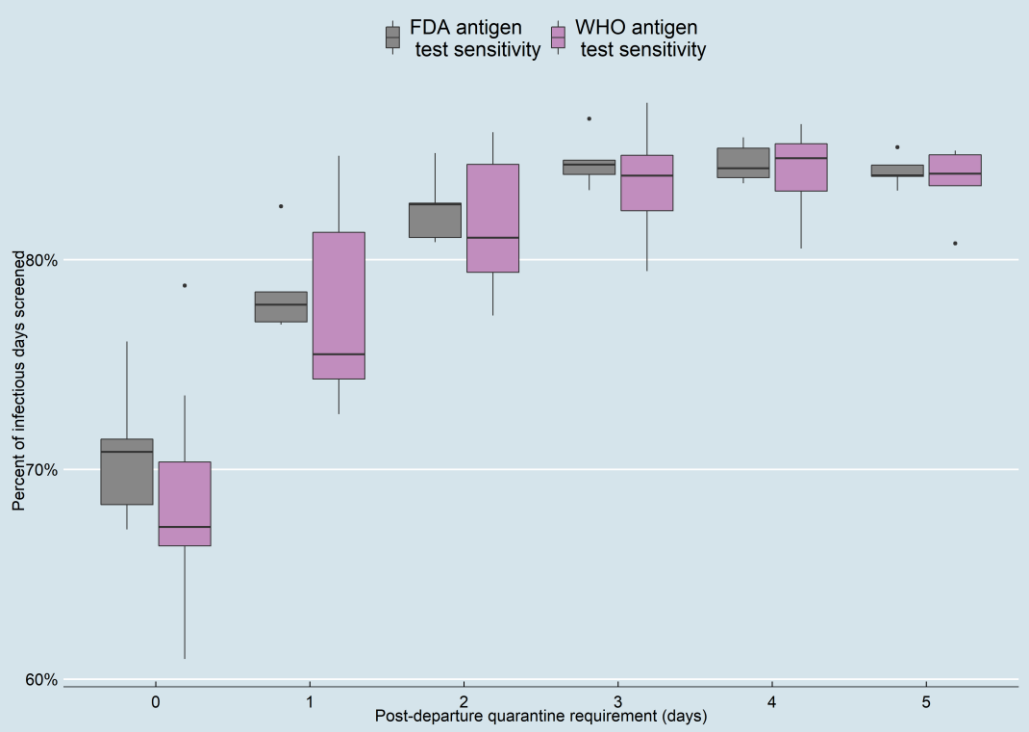
[50] Smith, L.E., Potts, H.W.W., Amlot, R., Fear, N.T., Michie, S. and Rubin, J. (2020), 'Adherence to the test, trace and isolate system: results from a time series of 21 nationally representative surveys in the UK (the COVID-19 Rapid Survey of Adherence to Interventions and Responses [CORSAIR] study)', September, https://doi.org/10.1101/2020.09.15.20191957

[51] See Oxera and Edge Health (2021), 'Assessment of the effectiveness of rapid testing for SARS-Cov-2'.

[52] Certain design features of antigen tests (e.g. whether colour or fluorescent indicators are used) can affect sensitivity.

[53] Populations with higher viral loads (e.g. patients with severe coronavirus symptoms) are more likely to test positive with an antigen test.

Figure 3.3 Relative performance of different antigen tests



Source: Oxera and Edge Health.

4 Conclusion

The analysis set out in this report demonstrates that single-testing schemes can screen a comparable proportion of infectious days to dual-testing schemes. For example, while a single antigen test administered on departure screens 62% of infectious days, two antigen tests administered 72 hours pre-departure and on departure screen 67% of infectious days. While a single on-departure test screens slightly fewer infectious days than a ten-day quarantine combined with a pre-departure test, it screens as many infectious days as a ten-day quarantine period alone. Our results are in line with other modelling evidence, which indicates that dual-testing may have a relatively small marginal benefit compared to single-testing. [54,55]

Due to the additional cost and logistical challenges to passengers of getting two tests rather than one, a single test close to the time of departure may be an appropriate option for passengers from most destinations who require testing (e.g. countries with low vaccination rates and high prevalence rates). In addition, as antigen tests are relatively rapid to administer and do not require the same level of technical expertise as PCR/LAMP testing, using an antigen test on departure (or close to the time of departure)[56] may present fewer operational challenges compared to PCR/LAMP.

Dual-testing schemes could instead be reserved for passengers from high-risk countries where prevalence of SARS-Cov-2 infections and/or variants of concern are high. For example, an antigen test administered 72 hours pre-departure combined with a LAMP or PCR test on day three would screen 85–87% of potentially infectious days from entering the community. This scheme therefore screens a very high proportion of infectious days, and reduces most of the risk of introducing variants of concern to the UK community. This is the case even when incorporating quarantine non-compliance, without onerous and costly hotel quarantine requirements.

For all testing schemes considered, the proportion of potentially infectious days per capita from air passengers from both the USA and the EU has been lower than UK infectious days even when prevalence in the USA/EU has been higher than in the UK. This is due to a combination of factors, such as many passengers spending at least some of their infectious days in their country of departure, some passengers choosing not to travel after developing symptoms consistent with COVID-19, and some passengers being screened out through testing.

In effect, even in the absence of testing, potential infectious days from air passengers coming from the USA or the EU represent a small share of the overall potential infectious days in the UK community. When the population is vaccinated, this relative risk decreases further so that testing may no longer be required for passengers coming from most destinations.

[54] Wells et al. (2020), 'Optimal COVID-19 quarantine and testing strategies', 28 October, https://www.medrxiv.org/content/10.1101/2020.10.27.20211631v1
[55] Clifford et al. (2020), 'Strategies to reduce the risk of SARS-CoV-2 re-introduction from international travellers', 25 July.
[56] Future modelling work could investigate dual-testing schemes where the first antigen test is administered closer to the time of departure than D-72 hours. Based on single-testing modelling results, administering antigen tests closer to the time of departure increases efficacy. This suggests that dual-testing schemes where the first antigen test is administered closer to the time of departure (rather than 72 hours before departure, as modelled in this report) could have increased efficacy as well.

A1 Air passenger modelling assumptions

In the tables below we set out the key assumptions used in this modelling. Where parameters have been changed from the initial model, they are bolded.

* Denotes no source.

Table A1.1 Key modelling assumptions—air passenger dual-testing model

Model input	Description
Number of people intending to fly	**Average monthly historical volumes from 2019 scaled to reflect 2020 volumes.[57]** **To reflect potential future airline volume increases as vaccinations are rolled out and protection to the domestic population increases, we present potential airline volumes between 10-30% higher than they were in 2020.**
Departure countries	EU and USA*
Duration of flight	Two hours for EU flights and eight hours for USA flights*
Proportion of infected passengers (prevalence estimates)	**Based on prevalence of the passenger's departure region (either USA or EU). Methodology from Russell et al. (2020) used to estimate under-ascertainment of SARS-CoV-2 cases in Europe and the USA. Figures updated to reflect prevalence when the difference in prevalence between the departure and arrival destinations was at its lowest, highest, and median values over the course of 2020.** **Underlying age/comorbidity structures and passenger demographics not considered[58]**
Proportion of asymptomatic cases	3-55% - Beta(1.9, 6.3), Median: 0.21, IQR: (0.12, 0.32), 95%: (0.03, 0.55) – derived from quantile matching, 95%: (0.03, 0.55)[59]
Incubation period (i.e. time from exposure to onset of symptom)	Gamma(μ = 5.5, σ^2 = 6.5) Median: 5.1 days IQR: (3.6, 6.9) days 95%: (1.7, 11.5) days Derived from quantile matching with Median: 5.1 days, 97.5%: 11.5 days[60]

[57] Airport data 2020 05 | UK Civil Aviation Authority [Internet]. [cited 2020 4 July]. Available from: https://www.caa.co.uk/Data-and-analysis/UK-aviation-market/Airports/Datasets/UK-Airport-data/Airport-data-2019/

[58] Russell, T.W., Golding, N., Hellewell, J., Abbott, S., Wright, L., Pearson, C.A.B., van Zandvoort, K., Jarvis, C.I., Gibbs, H., Yang, L., Eggo, R.M., Edmunds, J.W. and Kucharski, A.J. (2020), 'Reconstructing the early global dynamics of under-ascertained COVID-19 cases and infections', medRxiv 2020.07.07.20148460, https://doi.org/10.1101/2020.07.07.20148460

[59] Buitrago-Garcia DC, Egli-Gany D, Counotte MJ, Hossmann S, Imeri H, Ipekci AM, et al. The role of asymptomatic SARS-CoV-2 infections: rapid living systematic review and meta-analysis [Internet]. Epidemiology. medRxiv; 2020. Available from: https://www.medrxiv.org/content/10.1101/2020.04.25.20079103v2

[60] Lauer SA, Grantz KH, Bi Q, Jones FK, Zheng Q, Meredith HR, et al. The Incubation Period of Coronavirus Disease 2019 (COVID-19) From Publicly Reported Confirmed Cases: Estimation and Application. Ann Intern Med [Internet]. 2020 5 May;172(9):577–82. Available from: http://dx.doi.org/10.7326/M20-0504

Model input	Description
Infectious period	For symptomatic cases: Median: 7.1 days IQR: (5.7, 8.5) days 95%: (2.5, 11.6) days For asymptomatic cases: Gamma(μ = 6, σ^2 = 12) Median: 5.3 days IQR: (3.5, 7.8) days 95%: (1.2, 14.4) days[61]
Symptomatic period (i.e. time after onset of symptoms until no longer symptomatic)	Gamma(μ = 9.1, σ^2 = 14.7) Median: 8.6 days IQR: (6.3, 11.3) days 95%: (3.2, 18.0) days Derivation based on moment matching distributions[62]
RT-PCR sensitivity	Modelled as a function of the time since their exposure by fitting a Generalised Additive Model (GAM), with a binomial likelihood and penalised B-spline basis (P-spline), fitted to data collected by Grassly et al. (2020). As in Grassly et al. (2020), no assumptions are made on the relative sensitivity of RT-PCR tests for symptomatic/asymptomatic SARS-CoV-2 cases[63]
RT-LAMP testing sensitivity	A scaling factor for the relative effectiveness of RT-LAMP testing (0.9) compared to RT-PCR testing is applied to the RT-PCR test sensitivity distribution[64]

[61] Wölfel R, Corman VM, Guggemos W, Seilmaier M, Zange S, Müller MA, et al. Virological assessment of hospitalised patients with COVID-2019. Nature [Internet]. 2020 May;581(7809):465–9. Available from: http://dx.doi.org/10.1038/s41586-020-2196-x;
Byrne AW, McEvoy D, Collins A, Hunt K, Casey M, Barber A, et al. Inferred duration of infectious period of SARS-CoV-2: rapid scoping review and analysis of available evidence for asymptomatic and symptomatic COVID-19 cases [Internet]. Epidemiology. medRxiv; 2020. Available from: https://www.medrxiv.org/content/10.1101/2020.04.25.20079889v1

[62] Quilty BJ, Clifford S, Flasche S, Eggo RM, CMMID nCoV working group. Effectiveness of airport screening at detecting travellers infected with novel coronavirus (2019-nCoV). Euro Surveill [Internet]. 2020 Feb;25(5). Available from: http://dx.doi.org/10.2807/1560-7917.ES.2020.25.5.2000080;
Li Q, Guan X, Wu P, Wang X, Zhou L, Tong Y, et al. Early Transmission Dynamics in Wuhan, China, of Novel Coronavirus-Infected Pneumonia. N Engl J Med [Internet]. 2020 26 March;382(13):1199–207. Available from: http://dx.doi.org/10.1056/NEJMoa2001316

[63] https://www.thelancet.com/journals/laninf/article/PIIS1473-3099(20)30630-7/fulltext

[64] Isao Yokota, PhD, MPH, Peter Y Shane, MD, Kazufumi Okada, MPH, Yoko Unoki, BSN, Yichi Yang, MPH, Tasuku Inao, BS, Kentaro Sakamaki, PhD, MPH, Sumio Iwasaki, BS, Kasumi Hayasaka, Junichi Sugita, MD, PhD, Mutsumi Nishida, PhD, Shinichi Fujisawa, BS, Takanori Teshima, MD, PhD, Mass screening of asymptomatic persons for SARS-CoV-2 using saliva, Clinical Infectious Diseases, ciaa1388, https://doi.org/10.1093/cid/ciaa1388

Model input	Description
Antigen test sensitivity	**Antigen test sensitivity can vary significantly depending on the brand of test used, the population being tested and the time window post-infection in which the test is administered. The test we use in our analysis is referred to as the 'FDA-approved antigen test' throughout this report. It has the following reported sensitivities compared to PCR:** • **Pre-symptomatic: 80%** • **0-7 days post-symptom onset: 95%[65]** • **8+ days post-symptom onset: 80%** • **Asymptomatic: 80%** **As a sensitivity analysis, we also include a WHO-approved brand (referred to as WHO-approved antigen test throughout the paper). We scale PCR sensitivity by the following factors for this brand:** • **Pre-symptomatic: 66%**[66] • **0-7 days post-symptom onset: 86%[67]** • **8+ days post-symptom onset: 54%** • **Asymptomatic: 66%**
Air passenger quarantine compliance rate	**We extrapolate data on air passenger quarantine compliance over time available from the ONS and apply cumulative compliance values to quarantines with different durations. The survey reports: 72% of respondents definitely complying with quarantine by day 5, 71% of respondents definitely complying with quarantine by day 8, 58% of respondents complying by day 13.[68] We apply these quarantine compliance rates to symptomatic and asymptomatic passengers.**
Symptomatic quarantine compliance rate	**In addition to being required to quarantine due to travel, individuals are also asked to quarantine if they develop symptoms consistent with COVID-19 in most jurisdictions. Therefore, we include quarantining due to symptoms in our model. We set this at 18.2% for symptomatic individuals.[69] This is based on survey evidence in the UK population from King's College London.[70] This is applied to individuals both pre- and post- arrival in their travel destination.**
Syndromic screening rate	**18.2% of passengers that are symptomatic at the time of their flight decide not to travel, consistent with survey evidence from King's College London on symptomatic quarantine compliance.[71] As a sensitivity analysis, syndromic screening of 70% is included, reflecting early modelling on pre-departure screening.[72]**

[65] Pilarowski et Al., 'Field performance and public health response using the BinaxNOWTM Rapid SARS-CoV-2 antigen detection assay during community-based testing', 2020

[66] https://www.globalpointofcare.abbott/en/product-details/panbio-covid-19-ag-antigen-test.html

[67] Linares et Al. 'Panbio antigen rapid test is reliable to diagnose SARS-CoV-2 infection in the first 7 days after the onset of symptoms', Dec 4. 2020 https://www.sciencedirect.com/science/article/abs/pii/S1386653220304017?via%3Dihub

[68] Office for National Statistics (2020), 'Non-exempt international arrivals self-isolation behavioural survey pilot, UK, 30 September to 8 October 2020', 1 December, https://www.ons.gov.uk/peoplepopulationandcommunity/healthandsocialcare/conditionsanddiseases/adhocs/12575nonexemptinternationalarrivalsselfisolationbehaviouralsurveypilotuk30septemberto8october2020

[69] Quilty BJ, Clifford S, Flasche S, Eggo RM, CMMID nCoV working group. Effectiveness of airport screening at detecting travellers infected with novel coronavirus (2019-nCoV). Euro Surveill [Internet]. 2020 Feb;25(5). Available from: http://dx.doi.org/10.2807/1560-7917.ES.2020.25.5.2000080

[70] This has been updated from previously used international evidence based on the Norwegian population (based on a mix of individuals returning from international travel or being required to quarantine from contact tracing).

[71] This has been updated from previously used international evidence based on the Norwegian population (based on a mix of individuals returning from international travel or being required to quarantine from contact tracing).

[72] Gostic K, Gomez AC, Mummah RO, Kucharski AJ, Lloyd-Smith JO. Estimated effectiveness of symptom and risk screening to prevent the spread of COVID-19. Elife [Internet]. 2020 24 February;9. Available from: http://dx.doi.org/10.7554/eLife.55570

A2 Domestic modelling assumptions

Table A2.1 Key modelling assumptions—domestic (UK) infectious days model

Model input	Description
Proportion of infected population (prevalence estimates)	**The Office for National Statistics in the UK publishes weekly reports of the percentage of people in the community testing positive for SARS-CoV-2.[73] These estimates are made at the national level, which we use to calculate the UK community prevalence.**
Proportion of asymptomatic cases	3-55% - Beta(1.9, 6.3), Median: 0.21, IQR: (0.12, 0.32), 95%: (0.03, 0.55) – derived from quantile matching, 95%: (0.03, 0.55)[74]
Incubation period (i.e. time from exposure to onset of symptom)	Gamma(μ = 5.5, σ^2 = 6.5) Median: 5.1 days IQR: (3.6, 6.9) days 95%: (1.7, 11.5) days Derived from quantile matching with Median: 5.1 days, 97.5%: 11.5 days[75]
Infectious period	For symptomatic cases: Median: 7.1 days IQR: (5.7, 8.5) days 95%: (2.5, 11.6) days For asymptomatic cases: Gamma(μ = 6, σ^2 = 12) Median: 5.3 days IQR: (3.5, 7.8) days 95%: (1.2, 14.4) days[76]
Symptomatic period (i.e. time after onset of symptoms until no longer symptomatic)	Gamma(μ = 9.1, σ^2 = 14.7) Median: 8.6 days IQR: (6.3, 11.3) days 95%: (3.2, 18.0) days Derivation based on moment matching distributions[77]

[73] ONS Infection Survey data available from Office for National Statistics (2021), 'Coronavirus (COVID-19) Infection Survey, UK Statistical bulletins', https://www.ons.gov.uk/peoplepopulationandcommunity/healthandsocialcare/conditionsanddiseases/bulletins/coronaviruscovid19infectionsurveypilot/previousReleases

[74] Buitrago-Garcia DC, Egli-Gany D, Counotte MJ, Hossmann S, Imeri H, Ipekci AM, et al. The role of asymptomatic SARS-CoV-2 infections: rapid living systematic review and meta-analysis [Internet]. Epidemiology. medRxiv; 2020. Available from: https://www.medrxiv.org/content/10.1101/2020.04.25.20079103v2

[75] Lauer SA, Grantz KH, Bi Q, Jones FK, Zheng Q, Meredith HR, et al. The Incubation Period of Coronavirus Disease 2019 (COVID-19) From Publicly Reported Confirmed Cases: Estimation and Application. Ann Intern Med [Internet]. 2020 5 May;172(9):577–82. Available from: http://dx.doi.org/10.7326/M20-0504

[76] Wölfel R, Corman VM, Guggemos W, Seilmaier M, Zange S, Müller MA, et al. Virological assessment of hospitalised patients with COVID-2019. Nature [Internet]. 2020 May;581(7809):465–9. Available from: http://dx.doi.org/10.1038/s41586-020-2196-x;
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[77] Quilty BJ, Clifford S, Flasche S, Eggo RM, CMMID nCoV working group. Effectiveness of airport screening at detecting travellers infected with novel coronavirus (2019-nCoV). Euro Surveill [Internet]. 2020 Feb;25(5). Available from: http://dx.doi.org/10.2807/1560-7917.ES.2020.25.5.2000080;
Li Q, Guan X, Wu P, Wang X, Zhou L, Tong Y, et al. Early Transmission Dynamics in Wuhan, China, of Novel Coronavirus-Infected Pneumonia. N Engl J Med [Internet]. 2020 26 March;382(13):1199–207. Available from: http://dx.doi.org/10.1056/NEJMoa2001316

Model input	Description
RT-PCR sensitivity	Modelled as a function of the time since their exposure by fitting a Generalised Additive Model (GAM), with a binomial likelihood and penalised B-spline basis (P-spline), fitted to data collected by Grassly et al. (2020). As in Grassly et al. (2020), no assumptions are made on the relative sensitivity of RT-PCR tests for symptomatic/asymptomatic SARS-CoV-2 cases[78]
Compliance with getting tested if symptomatic	**Kings College London – 10.9%[79].**
Compliance rate	**18.2%[80] for symptomatic individuals, evidence from King's College London.**

[78] https://www.thelancet.com/journals/laninf/article/PIIS1473-3099(20)30630-7/fulltext
[79] 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
[80] Steens, A., Freiesleben de Blasio, B., Veneti, L., Gimma, A., Edmunds, J.W., Van Zandvoort, K., Jarvis, C.I., Forland, F. and Robberstad, (2020), 'Poor self-reported adherence to COVID-19-related quarantine/isolation requests, Norway, April to July 2020', Euro Surveill. 2020;25(37):pii=2001607, https://doi.org/10.2807/1560-7917.ES.2020.25.37.2001607

A3 Dual testing scheme efficacy with pre departure quarantine

Table A3.1 Dual-testing scheme efficacy with pre departure quarantine

		Second test type			
First test type	**Second test timing***	**PCR**	**LAMP**	**FDA-antigen**	**No test**
PCR	D=-72	-	-	-	61% (39%-80%)
	D=0	-	85% (69%-100%)	85% (69%-100%)	-
	A=0	90% (76%-99%)	88% (71%-100%)	87% (70%-100%)	-
	1	91% (78%-99%)	90% (77%-99%)	89% (74%-99%)	-
	2	90% (78%-99%)	90% (77%-99%)	89% (76%-98%)	-
	3	89% (77%-100%)	89% (76%-98%)	89% (76%-98%)	-
	4	87% (73%-97%)	87% (75%-97%)	87% (74%-97%)	-
	5	85% (71%-96%)	86% (72%-97%)	85% (72%-97%)	-
	10	-	-	-	75% (57%-92%)
LAMP	D=-72	-	-	-	57% (34%-76%)
	D=0	-	85% (69%-99%)	84% (65%-98%)	-
	A=0	89% (74%-99%)	87% (70%-100%)	86% (69%-100%)	-
	1	90% (77%-98%)	89% (75%-99%)	88% (74%-98%)	-
	2	90% (78%-97%)	89% (76%-98%)	88% (74%-97%)	-
	3	88% (76%-96%)	88% (74%-97%)	88% (74%-96%)	-
	4	86% (72%-96%)	86% (74%-97%)	86% (72%-95%)	-
	5	84% (70%-95%)	85% (72%-96%)	84% (70%-96%)	-
	10	-	-	-	74% (54%-92%)
FDA-antigen	D=-72	-	-	-	54% (29%-75%)
	D=0	-	84% (67%-100%)	83% (67%-96%)	-
	A=0	89% (74%-98%)	86% (69%-100%)	85% (69%-100%)	-
	1	90% (78%-99%)	89% (74%-99%)	88% (74%-98%)	-
	2	89% (77%-99%)	89% (76%-98%)	88% (74%-98%)	-
	3	87% (75%-97%)	87% (75%-96%)	88% (72%-97%)	-
	4	85% (72%-95%)	86% (74%-96%)	85% (71%-95%)	-
	5	83% (68%-95%)	83% (69%-96%)	83% (69%-95%)	-
	10	-	-	-	74% (54%-90%)

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