Effectiveness of quarantine and testing to prevent COVID-19 transmission from arriving travelers

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# Declarations

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# Background

COVID-19 outbreaks seeded by arriving travelers are concerning to all countries, particularly those with low community transmission. How to manage risk of SARS-CoV-2 transmission from arriving travelers is a critical policy question. A recent study estimated the distribution of incubation time for SARS-CoV-2 and conducted a probabilistic analysis of the number of symptomatic infections missed by active monitoring [1]. While relevant, their analysis did not consider transmission by asymptomatic and presymptomatic travelers, the role of non-compliance, nor the possible use of testing, limiting applicability to policy decisions around arriving travelers.

# Objective

We extended the prior analysis by evaluating policies that employ testing in addition to quarantine, by considering risk of presymptomatic and asymptomatic transmission, and by evaluating how quarantine and isolation compliance ifluenced community risk.

# Methods and findings

We compared the impact of 0 – 14 days of mandatory quarantine on the expected number of days at risk of community transmission per infected traveler (i.e., days when infectious and not in quarantine or isolation). In the base scenario, we assumed 80% of travelers quarantined, 80% isolated when symptomatic, 90% isolated after testing positive without symptoms, and 100% isolated after testing positive when symptomatic. For scenarios with testing we assumed PCR testing 24 hours before the end of quarantine and we assumed travelers who did not comply with quarantine were not tested. We assumed a sensitivity of 70% in presymptomatic- and symptomatic-infectious individuals and 60% in asymptomatic-infectious individuals (sensitivity for asymptomatic infections is poorly understood but possibly lower).

We used code from Lauer 2020 to sample 1,000 bootstrapped lognormal parameters for the incubation time distribution [1]. Following Moghadas 2020, we used gamma distributions for the durations of asymptomatic-infectious, presymptomatic-infectious, and symptomatic-infectious phases, and we truncated the presymptomatic-infectious distribution from 0.8 to 3 days [2]. We introduced uncertainty into distributions from Moghadas 2020 by varying the mean and standard deviation uniformly by ±20% and sampled 1000 parameter sets for each distribution (Figure S1). For 1,000 sets of duration distributions, we simulated 1000 travelers with asymptomatic infection and determined the time infectiousness began () and the time infectiousness ended (), and we simulated 6000 travelers with symptomatic infection for whom we determined the time symptoms began () in addition to and . At arrival (), infected travelers were equally likely to be at any point of their infection from to . Using expressions in the supplement, we calculated the average days at risk across all infected travelers and calculated the expected value by weighting by the percent asymptomatic infections (24% in base scenario; average of two values used in [2]).

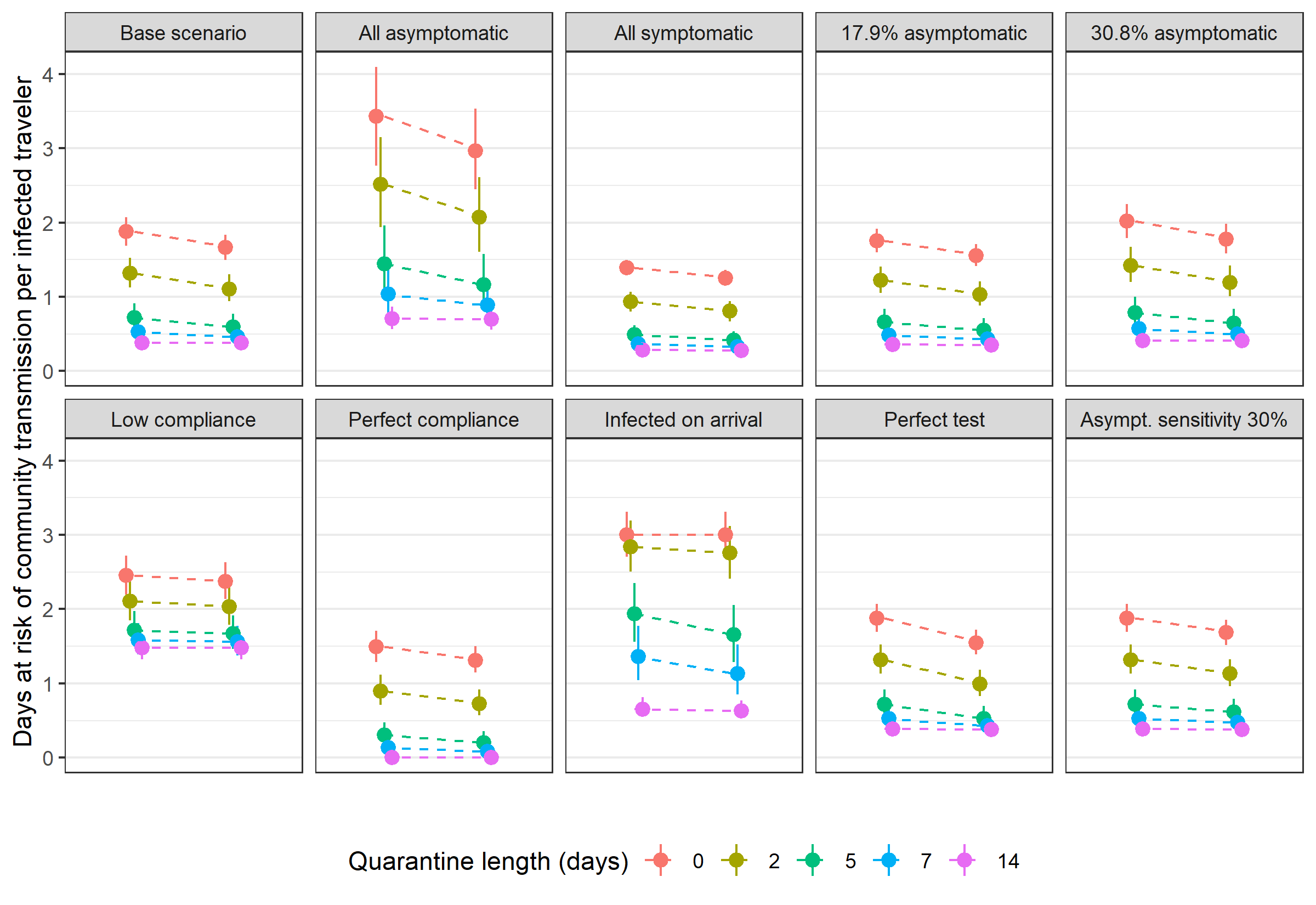
In the base scenario, infected travelers were at risk of community transmission 1.7 – 2.1 days on average (Figure 1; Table S2). Even a two-day quarantine (1.1 – 1.5 days at risk) was more effective than testing alone (1.5 – 1.8 days at risk). The addition of testing had diminishing benefit as the length of quarantine increased (reduction of 0.2, 0.06, and 0.003 days at risk for 2, 7, and 14-day quarantine, respectively). Compliance greatly influenced risk: a 14-day quarantine resulted in 1.3 - 1.6 days at risk assuming low compliance compared to 0 - 0.03 days assuming perfect compliance. If travelers were infected immediately before arriving, the days at risk would be 60% higher than the basecase assuming no intervention, and testing without quarantine would have little benefit.

As shown in Figure 2, the person-days at risk of community transmission per 10,000 infected travelers depends on the prevalence. The expected number of secondary infections per 10,000 travelers depends on both prevalence and the rate of secondary infections per infected day in the community.

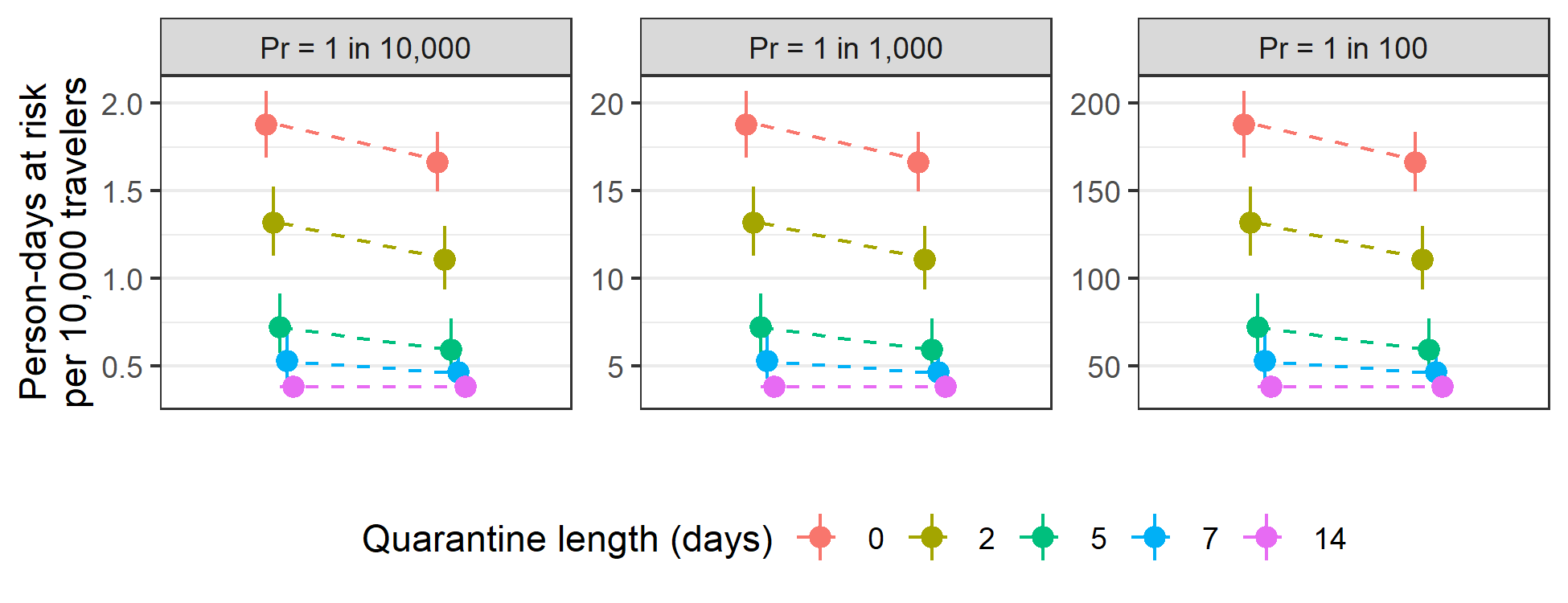
# Discussion

Quarantine is more effective than testing to reduce risk of transmission from arriving travelers. Testing can add value when longer quarantine is infeasible, but the benefits of testing diminish with quarantine length. Measures to increase compliance with quarantine and isolation guidelines can significantly reduce risk. We did not consider household transmission during quarantine, a substantial risk for countries with less strict quarantine requirements.

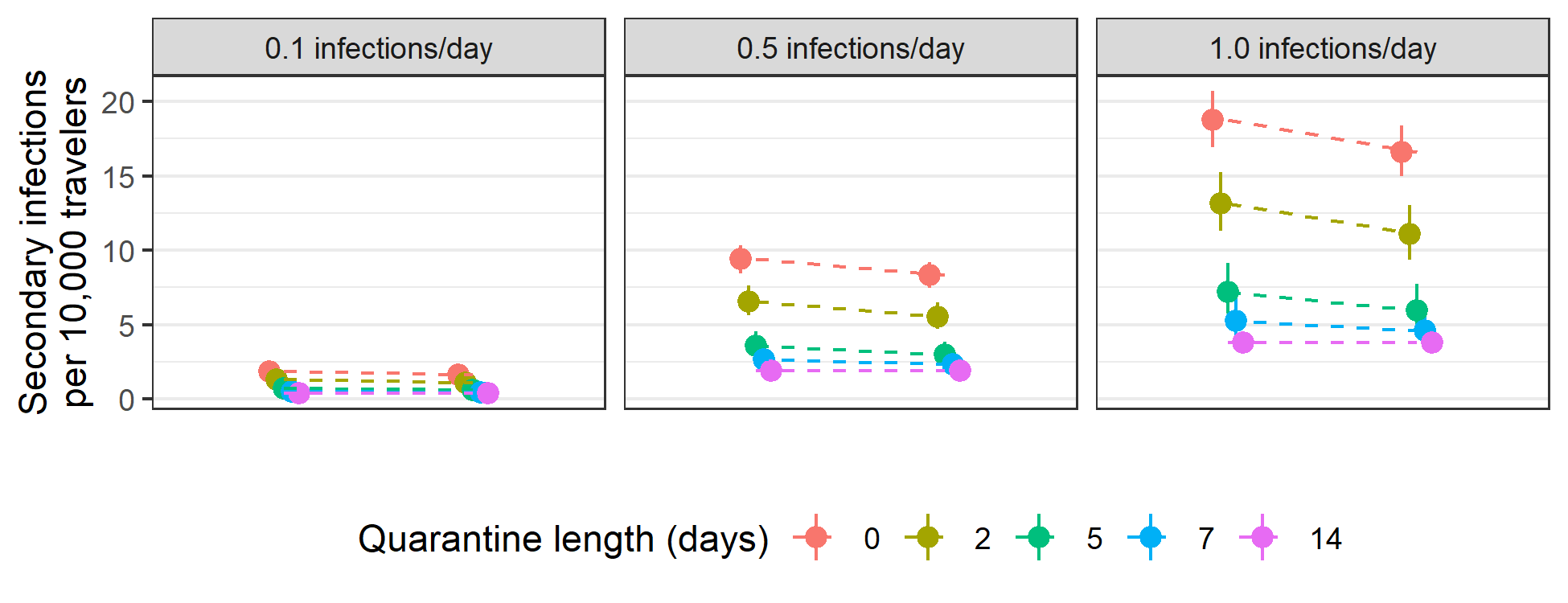
**Fig. 1** Expected days at risk of community transmission risk per infectious traveler for ten scenarios. Points indicates the median and bars indicate 98% credible interval for each estimate. “Low compliance” scenario assumes 40% of travelers comply with quarantine, 50% isolate with symptoms or a positive test, and 70% isolate with both symptoms and a positive test. Abbreviations: asympt, asymptomatic.



**Fig. 2** Person-days at risk of community transmission per 10,000 arriving travelers for each policy by SARS-CoV-2 prevalence among travelers (base scenario). Points indicates the median and bars indicate 98% credible interval for each estimate. Abbreviations: Pr, prevalence of pre-infectious or infectiousness with SARS-CoV-2.



**Fig. 3** Secondary cases per 10,000 travelers for each policy by expected number of secondary infections per infectious person-day in community (base scenario). Assuming SARS-CoV-2 prevalence of 1 in 1,000 travelers. Points indicates the median and bars indicate 98% credible interval for each estimate.



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# References

1. Lauer SA, Grantz KH, Bi Q, et al. The incubation period of coronavirus disease 2019 (CoVID-19) from publicly reported confirmed cases: Estimation and application. *Annals of Internal Medicine*. 2020;172(9):577-582. doi:[10.7326/M20-0504](https://doi.org/10.7326/M20-0504)

2. Moghadas SM, Fitzpatrick MC, Sah P, et al. The implications of silent transmission for the control of COVID-19 outbreaks. *Proceedings of the National Academy of Sciences*. 2020;117(30):17513-17515. doi:[10.1073/pnas.2008373117](https://doi.org/10.1073/pnas.2008373117)

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Effectiveness of quarantine and testing to limit new COVID-19 cases from arriving travelers

Supplement

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# Calculation of days at risk based on quarantine duration and testing

We calculated the expected number of days at risk of community transmission for each person with an active SARS-CoV-2 infection (either pre-infectious or infectious) using the expressions below. In the expressions below, time is with respect to the time of infection .

**Asymptomatic infections** Travelers with asymptomatic infection comply with quarantine with probability . If they do not comply, they will be infectious in the community from the greater of the time they become infectious () and the time they arrive (), and their “infectious days in community” will end when they recover, . If they comply with quarantine, their infectious days will begin at the greater of and quarantine ends, represented by . Therefore, the expected number of days at risk of community transmission for asymptomatic individuals without testing is:

In policies with testing, we assume those who do not comply with quarantine also do not receive testing. Those who are compliant are tested 1 day before quarantine end (). If they are tested before infectious () they will test negative and be at risk of community transmission from the greater of and until . If they are tested while infectious, they will only be at risk of community transmission if they test false-negative (probability where is test sensitivity during the asymptomatic-infectious stage) or if they test positive but refuse to quarantine ( where is probability of isolation given a positive test and no symptoms). Therefore, the expected number of days at risk of community transmission for asymptomatic individuals with testing is:

**Symptomatic infections** For travelers with symptomatic infections we calculate the days at risk of community transmission separately for the presymptomatic and symptomatic disease stages. Days at risk during the presymptomatic stage are calculated the same as asymptomatic days except that the endpoint for presymptomatic days at risk is the time that symptoms begin () rather than the time of recovery (), and we use test sensitivity for detecting disease in the presymptomatic-infectious stage (). Therefore, the expected number of days at risk of community transmission while in presymptomatic phase without testing is:

With testing, it becomes:

We assume travelers will isolate while in symptomatic-infectious stage with probability . Days at risk while symptomatic begin at , the time symptoms begin, and end at , the time of recovery when individuals are no longer infectious. Therefore, the expected number of days at risk of community transmission while in symptomatic phase without testing is:

In policies with testing, we assume that the days at risk for those who do not comply with quarantine (probability ) is unchanged because they also do not get tested. For those who comply, if they are tested before infectious () then they will test negative. With probability they will not isolate and incur days at risk until . If tested duirng presymptomatic-infectious stage (), they will incur days at risk while symptomatic only if they test false negative (probability ) and they do not isolate (probability )). We assume all travelers with both symptoms and a positive test will isolate. For those tested while symptomatic, they will incur days at risk only if the test is false negative ( where is test sensitivity for those in symptomatic-infectious state). Therefore, the expected number of days at risk of community transmission while in the symptomatic-infectious phase with testing is:

**Table S1** Expected days at risk of community transmission risk per infectious traveler for ten scenarios based on quarantine length and testing. Median and 98% credible interval provided. Abbreviations: asympt, asymptomatic; T, test used; NT, no testing used.

| **Scenario** | **Test** | **0 days** | **2 days** | **5 days** | **7 days** | **14 days** |
| --- | --- | --- | --- | --- | --- | --- |
| Base scenario | NT | 1.9 (1.7 - 2.1) | 1.3 (1.1 - 1.5) | 0.72 (0.58 - 0.92) | 0.53 (0.43 - 0.69) | 0.38 (0.34 - 0.44) |
| T | 1.7 (1.5 - 1.8) | 1.1 (0.94 - 1.3) | 0.59 (0.47 - 0.77) | 0.46 (0.38 - 0.60) | 0.38 (0.34 - 0.43) |
| All asymptomatic | NT | 3.4 (2.8 - 4.1) | 2.5 (1.9 - 3.2) | 1.4 (1.0 - 2.0) | 1.0 (0.74 - 1.4) | 0.70 (0.56 - 0.87) |
| T | 3.0 (2.4 - 3.5) | 2.1 (1.6 - 2.6) | 1.2 (0.84 - 1.6) | 0.89 (0.65 - 1.2) | 0.69 (0.56 - 0.85) |
| All symptomatic | NT | 1.4 (1.3 - 1.5) | 0.94 (0.80 - 1.1) | 0.49 (0.39 - 0.62) | 0.36 (0.30 - 0.47) | 0.28 (0.26 - 0.31) |
| T | 1.2 (1.2 - 1.4) | 0.81 (0.67 - 0.94) | 0.41 (0.33 - 0.54) | 0.33 (0.28 - 0.42) | 0.28 (0.26 - 0.31) |
| 17.9% asymptomatic | NT | 1.8 (1.6 - 1.9) | 1.2 (1.1 - 1.4) | 0.66 (0.53 - 0.84) | 0.49 (0.40 - 0.63) | 0.36 (0.32 - 0.41) |
| T | 1.6 (1.4 - 1.7) | 1.0 (0.88 - 1.2) | 0.55 (0.44 - 0.71) | 0.43 (0.36 - 0.55) | 0.35 (0.32 - 0.40) |
| 30.8% asymptomatic | NT | 2.0 (1.8 - 2.2) | 1.4 (1.2 - 1.7) | 0.79 (0.62 - 1.0) | 0.57 (0.46 - 0.75) | 0.41 (0.36 - 0.48) |
| T | 1.8 (1.6 - 2.0) | 1.2 (1.0 - 1.4) | 0.64 (0.51 - 0.84) | 0.50 (0.41 - 0.65) | 0.41 (0.36 - 0.47) |
| Low compliance | NT | 2.5 (2.2 - 2.7) | 2.1 (1.8 - 2.4) | 1.7 (1.5 - 2.0) | 1.6 (1.4 - 1.8) | 1.5 (1.3 - 1.6) |
| T | 2.4 (2.1 - 2.6) | 2.0 (1.8 - 2.3) | 1.7 (1.5 - 1.9) | 1.6 (1.4 - 1.8) | 1.5 (1.3 - 1.6) |
| Perfect compliance | NT | 1.5 (1.3 - 1.7) | 0.90 (0.71 - 1.1) | 0.31 (0.18 - 0.47) | 0.13 (0.061 - 0.26) | 0.0044 (0 - 0.030) |
| T | 1.3 (1.1 - 1.5) | 0.72 (0.57 - 0.92) | 0.20 (0.11 - 0.36) | 0.079 (0.029 - 0.19) | 0.0024 (0 - 0.021) |
| Infected on arrival | NT | 3.0 (2.7 - 3.3) | 2.8 (2.5 - 3.2) | 1.9 (1.6 - 2.3) | 1.4 (1.0 - 1.8) | 0.65 (0.56 - 0.81) |
| T | 3.0 (2.7 - 3.3) | 2.8 (2.4 - 3.1) | 1.7 (1.3 - 2.1) | 1.1 (0.85 - 1.5) | 0.63 (0.56 - 0.77) |
| Perfect test | NT | 1.9 (1.7 - 2.1) | 1.3 (1.1 - 1.5) | 0.72 (0.58 - 0.92) | 0.53 (0.43 - 0.69) | 0.38 (0.34 - 0.44) |
| T | 1.5 (1.4 - 1.7) | 0.99 (0.83 - 1.2) | 0.52 (0.41 - 0.70) | 0.43 (0.36 - 0.55) | 0.38 (0.34 - 0.42) |
| Asympt. sensitivity 30% | NT | 1.9 (1.7 - 2.1) | 1.3 (1.1 - 1.5) | 0.72 (0.58 - 0.92) | 0.53 (0.43 - 0.69) | 0.38 (0.34 - 0.44) |
| T | 1.7 (1.5 - 1.9) | 1.1 (0.96 - 1.3) | 0.61 (0.49 - 0.79) | 0.47 (0.39 - 0.61) | 0.38 (0.34 - 0.43) |

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**Figure S1:** Sample of 100 distributions for durations. Incubation time (top-left) generated using code from Lauer 2020 [1] that generates bootstrapped posterior distributions from their parametric accelerated failure time model calibration. Other distributions generated by varying the mean and variance of distributions from Moghadas 2020 [2] by ±20% and converting to gamma distribution parameters using the relationships and where and are the mean and variance of the gamma distribution and and are the shape and scale parameters.

