

The Impacts of Simultaneous Disease Intervention Decisions on Epidemic Outcomes - Supplementary Information

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1 Asymptomatic Cases

2 Asymptomatic infections can be prevalent in many diseases, and we thus explore the impact of
3 asymptomatic cases in our model. In these analyses, we use an asymptomatic probability of 50%
4 for infectious cases, and assume an asymptomatic individual is as infectious as a symptomatic one.
5 We also recalibrate parameters to maintain epidemic outcomes similar to the baseline scenario while
6 maintaining the baseline transmission rate of 0.005. In this scenario, we use parameter values of
7 $\lambda = 2.85$, $\gamma = 0.75$, $\theta = 0.403$, and the remaining parameters at baseline values. This will allow us
8 to directly compare the impact of asymptomatic infections.

9 With low transmission rate, vaccination delay does not impact epidemic size when NPIs are
10 used. (Table 1). When NPIs are not used, epidemic size is minimally affected ($\approx 2.4\%$ difference
11 between no vaccine delay and a 60 day vaccine delay.) With baseline transmission rate, the difference
12 becomes larger (Table 2). With NPIs, final size changes by under 1 percentage point, but without
13 NPIs, the difference is $\approx 8.5\%$. Finally, with a higher transmission rate of $\beta = 0.006$ (Table 3), NPIs
14 cause the final size to change $\approx 2.4\%$ across all vaccine delays, whereas without NPI effects, final
15 size changes by $\approx 12\%$.

16 Thus, we observe similar effects of NPIs on epidemic final size when there are vaccine delays with
17 asymptomatic cases as we saw without. That is, changes in final size between no delay and longer
18 delays are much smaller when NPIs are incorporated than when they are not.

19 Considering the effects of differing vaccine efficacy on epidemic outcomes, we see similar results
20 to the case with no asymptomatic infections. With NPIs used in the population, symptomatic
21 epidemic size and vaccine uptake do not show a large change across vaccine efficacies ($\approx 0.3\%$ and
22 2% , respectively) compared to when NPIs are not included (2.4% difference for final size and 4.5%
23 difference for vaccine uptake, see Tables 4 and 5).

24 In general, the main qualitative results are similar to when there are asymptomatic infections
25 to when there are not. When NPIs are included, vaccine availability delays and changes in vaccine
26 efficacy do not change epidemic final size and vaccine uptake as significantly compared to scenarios
27 where NPIs are not incorporated.

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Table 1: Epidemic final sizes (symptomatic cases only) with delayed vaccine availability. $\beta = 0.004$

Delay	Final Size (with NPIs) $\pm 95\%$ CI	Final Size (without NPIs) $\pm 95\%$ CI
0	0.03839 ± 0.0025	0.0932 ± 0.0013
10	0.0381 ± 0.0026	0.0924 ± 0.0014
20	0.0395 ± 0.0024	0.0933 ± 0.0012
30	0.0397 ± 0.0024	0.0940 ± 0.0023
40	0.04086 ± 0.0025	0.1010 ± 0.0019
50	0.04105 ± 0.0023	0.1108 ± 0.0024
60	0.03953 ± 0.0025	0.1173 ± 0.0029

Table 2: Epidemic final sizes (symptomatic cases only) with delayed vaccine availability. $\beta = 0.005$

Delay	Final Size (with NPIs) $\pm 95\%$ CI	Final Size (without NPIs) $\pm 95\%$ CI
0	0.0816 ± 0.0016	0.1107 ± 0.0006127
10	0.0826 ± 0.0013	0.1111 ± 0.0006301
20	0.0821 ± 0.0012	0.1145 ± 0.0007419
30	0.0817 ± 0.0013	0.1313 ± 0.0022
40	0.0838 ± 0.0014	0.1648 ± 0.0031
50	0.0847 ± 0.0018	0.1855 ± 0.0031
60	0.0864 ± 0.0015	0.1958 ± 0.0023

Table 3: Epidemic final sizes (symptomatic cases only) with delayed vaccine availability. $\beta = 0.006$

Delay	Final Size (with NPIs) $\pm 95\%$ CI	Final Size (without NPIs) $\pm 95\%$ CI
0	0.0987 ± 0.0006992	0.1236 ± 0.0006546
10	0.0985 ± 0.0006611	0.1225 ± 0.0006434
20	0.0994 ± 0.0006425	0.1373 ± 0.0016
30	0.1059 ± 0.0009648	0.1898 ± 0.0038
40	0.1130 ± 0.0013	0.2288 ± 0.0027
50	0.1202 ± 0.0013	0.2407 ± 0.0017
60	0.1228 ± 0.0014	0.2451 ± 0.0011

Table 4: Epidemic final sizes corresponding to vaccine efficacy (symptomatic cases only).

Efficacy	Final Size (With NPIs) $\pm 95\%$ CI	Final Size (Without NPIs) $\pm 95\%$ CI
0.5	0.0845 ± 0.0012	0.1350 ± 0.0008755
0.6	0.0835 ± 0.0014	0.1291 ± 0.0007565
0.7	0.0819 ± 0.0019	0.1231 ± 0.0007093
0.8	0.0819 ± 0.0013	0.1186 ± 0.0008193
0.9	0.0826 ± 0.0013	0.1145 ± 0.0006082
1.0	0.0814 ± 0.0014	0.1111 ± 0.0022

Table 5: Population vaccine uptake corresponding to vaccine efficacy.

Efficacy	Vaccine Uptake (With NPIs) $\pm 95\%$ CI	Vaccine Uptake (Without NPIs) $\pm 95\%$ CI
0.5	0.4662 ± 0.018	0.7124 ± 0.0037
0.6	0.4604 ± 0.0201	0.7051 ± 0.0036
0.7	0.4449 ± 0.0223	0.6938 ± 0.0037
0.8	0.4408 ± 0.019	0.6850 ± 0.0053
0.9	0.4503 ± 0.019	0.6784 ± 0.0036
1.0	0.4478 ± 0.02	0.6676 ± 0.013

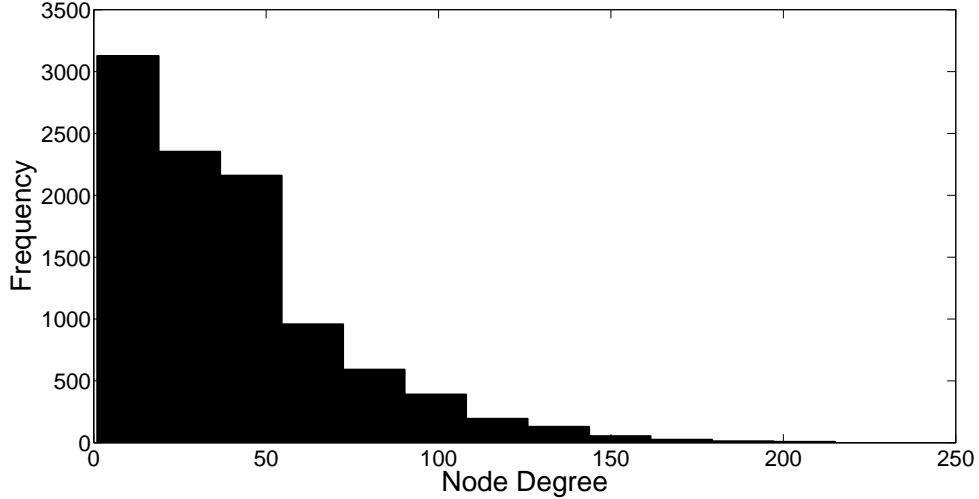


Figure 1: Frequency of node degrees in the empirically based network. The majority of nodes have a degree < 75 , whereas fewer nodes have higher degrees. The average node degree is 38.645.

29 Different network types will have an impact on epidemic outcomes due to contact structures
 30 playing a pivotal role in disease transmission. In our model, we initially used an empirically based
 31 network. Here, we will look at results stemming from a random network and a power law network.
 32 For these two types of networks, we recalibrate the parameters to achieve similar baseline scenarios
 33 to the outcomes corresponding to the empirical network.

34 For the random networks, we use the same average node degree seen in the empirically based
 35 network (Figure 1), and we generate new networks each simulation. The parameters used to obtain
 36 the same epidemic outcomes as the original baseline scenario are $\lambda = 1.75$, $\gamma = 0.25$, $\theta = 0.28$,
 37 $\beta = 0.00585$, and the remaining parameters at baseline values. We note that the transmission rate
 38 must be higher with this network structure to achieve the same epidemic final size, and in turn the
 39 same vaccine uptake, and NPI use as the empirical network. When either increasing or decreasing
 40 the transmission rate, we still use intervals of size 0.001.

41 With low transmission rate, vaccination delay does not significantly impact epidemic size when
 42 NPIs are used. (Table 6). With a transmission rate of $\beta = 0.00585$, the difference becomes larger
 43 (Table 7). With NPIs, final size changes by under 1 percentage point, but without NPIs, the
 44 difference is $\approx 18\%$, and the difference grows larger the later the vaccine is made available. Finally,
 45 with a higher transmission rate of $\beta = 0.00685$ (Table 8), NPIs cause the final size to change $\approx 10\%$
 46 across all vaccine delays, whereas without NPI effects, final size changes by $\approx 41\%$.

47 Considering the effects of differing vaccine efficacy on epidemic outcomes in the random net-
 48 works, we see similar results to the case with an empirically based network. With NPIs used in
 49 the population, epidemic size and vaccine uptake show changes across vaccine efficacies of $\approx 0.55\%$
 50 and 16% , respectively, compared to when NPIs are not included (3.4% difference for final size and
 51 only 1% difference for vaccine uptake, see Tables 9 and 10). An interesting dynamic occurs in the

Table 6: Epidemic final sizes with delayed vaccine availability (random network). $\beta = 0.00485$

Delay	Final Size (with NPIs) $\pm 95\%$ CI	Final Size (without NPIs) $\pm 95\%$ CI
0	0.0608 ± 0.0047	0.1543 ± 0.0044
10	0.05964 ± 0.0047	0.1527 ± 0.0049
20	0.06297 ± 0.0047	0.1525 ± 0.0054
30	0.0602 ± 0.0049	0.1500 ± 0.0063
40	0.06353 ± 0.0045	0.1545 ± 0.0052
50	0.0602 ± 0.0046	0.1523 ± 0.005
60	0.0602 ± 0.0048	0.1539 ± 0.0049

Table 7: Epidemic final sizes with delayed vaccine availability (random network). $\beta = 0.00585$

Delay	Final Size (with NPIs) $\pm 95\%$ CI	Final Size (without NPIs) $\pm 95\%$ CI
0	0.1592 ± 0.0015	0.1821 ± 0.0005972
10	0.1591 ± 0.0016	0.1818 ± 0.0005030
20	0.1592 ± 0.0014	0.1816 ± 0.00053807
30	0.1610 ± 0.0013	0.1823 ± 0.0007169
40	0.1602 ± 0.0017	0.2074 ± 0.0062
50	0.1609 ± 0.002	0.2911 ± 0.011
60	0.1649 ± 0.0027	0.3667 ± 0.012

Table 8: Epidemic final sizes with delayed vaccine availability (random network). $\beta = 0.00685$

Delay	Final Size (with NPIs) $\pm 95\%$ CI	Final Size (without NPIs) $\pm 95\%$ CI
0	0.1779 ± 0.0005021	0.1927 ± 0.0009735
10	0.1781 ± 0.0004927	0.1932 ± 0.001
20	0.1776 ± 0.0004817	0.1933 ± 0.0009566
30	0.1798 ± 0.0012	0.2634 ± 0.0091
40	0.2116 ± 0.0038	0.4638 ± 0.011
50	0.2524 ± 0.0042	0.5780 ± 0.0063
60	0.2739 ± 0.0033	0.6100 ± 0.0042

52 random network as although final size difference for the range of vaccine efficacy given in tables 9
 53 and 10 with NPIs is much smaller than when there are no NPIs, vaccine uptake increases much
 54 more. However, with NPIs, vaccine uptake amongst the population is approximately 20-40% lower
 55 than with no NPIs, and produces smaller epidemic sizes.

56 For the power law networks, we use a Barabási-Albert algorithm with three initial connected
 57 nodes to create a contact network for each simulation. The parameters used to obtain the same
 58 epidemic outcomes as the original baseline scenario are $\lambda = 1.25$, $\gamma = 0.5$, $\theta = 0.35$, $\beta = 0.075$, and
 59 the remaining parameters at baseline values. We note that the transmission rate must be higher with
 60 this network structure to achieve the same epidemic final size, and in turn the same vaccine uptake,

Table 9: Epidemic final sizes corresponding to vaccine efficacy (random network).

Efficacy	Final Size (With NPIs) $\pm 95\%$ CI =	Final Size (Without NPIs) $\pm 95\%$ CI
0.5	0.1644 ± 0.001	0.2158 ± 0.0009870
0.6	0.1616 ± 0.0014	0.2059 ± 0.0007589
0.7	0.1617 ± 0.0011	0.1978 ± 0.0006078
0.8	0.1609 ± 0.001	0.1904 ± 0.0005643
0.9	0.1603 ± 0.001	0.1858 ± 0.0004162
1.0	0.1589 ± 0.001	0.1821 ± 0.0004704

Table 10: Population vaccine uptake corresponding to vaccine efficacy (random network).

Efficacy	Vaccine Uptake (With NPIs) $\pm 95\%$ CI	Vaccine Uptake (Without NPIs) $\pm 95\%$ CI
0.5	0.5940 ± 0.039	0.8176 ± 0.0003564
0.6	0.5505 ± 0.041	0.8159 ± 0.0003212
0.7	0.5286 ± 0.042	0.8137 ± 0.0003098
0.8	0.4762 ± 0.042	0.8112 ± 0.0002534
0.9	0.4546 ± 0.042	0.8089 ± 0.0002167
1.0	0.4323 ± 0.043	0.8067 ± 0.0002177

61 and NPI use as the empirical network. When either increasing or decreasing the transmission rate,
 62 we will use intervals of size 0.02.

63 With a transmission rate of 0.0055, vaccination delay impacts epidemic size by $\approx 4\%$ when NPIs
 64 are used and ≈ 11 when they are not (Table 11). With a transmission rate of $\beta = 0.075$, the
 65 difference becomes larger (Table 12). With NPIs, final size changes by about 9 percentage points,
 66 but without NPIs, the difference is $\approx 23\%$. For both cases, the difference grows larger in the early
 67 stages of the epidemic. Finally, with a higher transmission rate of $\beta = 0.0095$ (Table 13), NPIs
 68 cause the final size to change $\approx 15\%$ across all vaccine delays, whereas without NPI effects, final
 69 size changes by $\approx 31\%$. Again, NPIs reduce epidemic sizes, as well as decrease the change in final
 70 size induced by delays in vaccine availability. In the scale free networks we created, the majority of
 71 epidemic incidence increase occurs before the 30 day mark of vaccination absence.

Table 11: Epidemic final sizes with delayed vaccine availability (power law network). $\beta = 0.055$

Delay	Final Size (with NPIs) $\pm 95\%$ CI	Final Size (without NPIs) $\pm 95\%$ CI
0	0.1231 ± 0.0014	0.1736 ± 0.000806
10	0.1282 ± 0.0028	0.1805 ± 0.0012
20	0.1411 ± 0.0033	0.2242 ± 0.0038
30	0.1623 ± 0.0017	0.2644 ± 0.0043
40	0.1607 ± 0.0021	0.2822 ± 0.006
50	0.1628 ± 0.0018	0.2869 ± 0.0027
60	0.1638 ± 0.002	0.2875 ± 0.0028

Table 12: Epidemic final sizes with delayed vaccine availability (power law network). $\beta = 0.075$

Delay	Final Size (with NPIs) $\pm 95\%$ CI	Final Size (without NPIs) $\pm 95\%$ CI
0	0.1685 ± 0.0008614	0.2053 ± 0.0013
10	0.1755 ± 0.0011	0.2253 ± 0.0023
20	0.2318 ± 0.0029	0.3602 ± 0.0057
30	0.2520 ± 0.002	0.4276 ± 0.0028
40	0.2565 ± 0.002	0.4306 ± 0.0024
50	0.2576 ± 0.002	0.4344 ± 0.0029
60	0.2599 ± 0.0021	0.4330 ± 0.0023

Table 13: Epidemic final sizes with delayed vaccine availability (power law network). $\beta = 0.095$

Delay	Final Size (with NPIs) $\pm 95\%$ CI	Final Size (without NPIs) $\pm 95\%$ CI
0	0.1921 ± 0.0011	0.2316 ± 0.0023
10	0.2124 ± 0.0023	0.2823 ± 0.0057
20	0.3136 ± 0.0031	0.4975 ± 0.0044
30	0.3346 ± 0.0025	0.5418 ± 0.0026
40	0.3427 ± 0.0022	0.5502 ± 0.0026
50	0.3401 ± 0.0021	0.5444 ± 0.0024
60	0.3426 ± 0.002	0.5442 ± 0.0026

72 Considering the effects of differing vaccine efficacy on epidemic outcomes in the power law net-
 73 works, we see similar results to the case with an empirically based network. With NPIs used in the
 74 population, epidemic size and vaccine uptake show changes across vaccine efficacies of $\approx 3.6\%$ and
 75 2% , respectively, compared to when NPIs are not included (8.8% difference for final size and 4.4%
 76 difference for vaccine uptake, see Tables 9 and 10).

Table 14: Epidemic final sizes corresponding to vaccine efficacy (power law network).

Efficacy	Final Size (With NPIs) $\pm 95\%$ CI	Final Size (Without NPIs) $\pm 95\%$ CI
0.5	0.2040 ± 0.0014	0.2941 ± 0.0017
0.6	0.1982 ± 0.0011	0.2751 ± 0.0016
0.7	0.1922 ± 0.0011	0.2557 ± 0.0014
0.8	0.1816 ± 0.0009980	0.2381 ± 0.0014
0.9	0.1762 ± 0.0008868	0.2219 ± 0.0014
1.0	0.1682 ± 0.0007904	0.2060 ± 0.0013

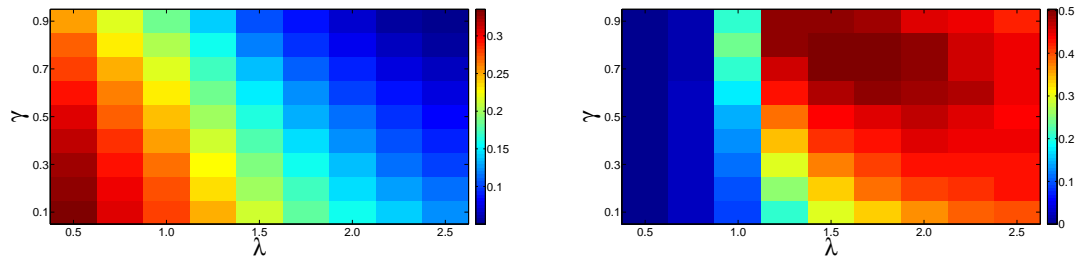
77 We have seen with these two alternate types of networks that the main results consistently hold.
 78 However, each network has unique dynamics that must be taken into account in certain scenarios.
 79 Thus, assumptions about network structure and transmission are an important consideration par-
 80 ticularly when modelling a specific disease. For example, a transmission network for influenza likely
 81 has a different structure than one that would be used to model HIV transmission.

Table 15: Population vaccine uptake corresponding to vaccine efficacy (power law network).

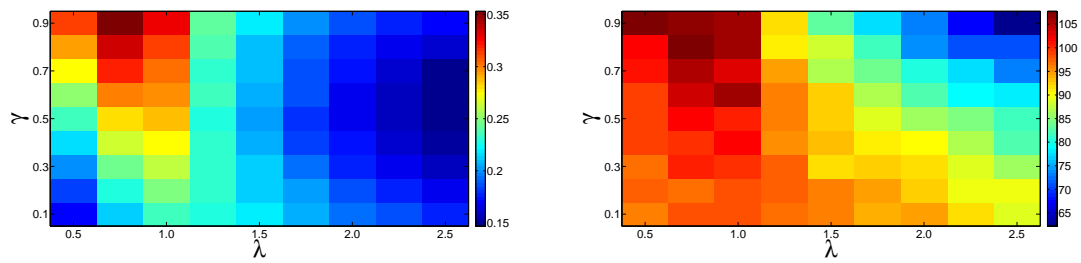
Efficacy	Vaccine Uptake (With NPIs) $\pm 95\%$ CI	Vaccine Uptake (Without NPIs) $\pm 95\%$ CI
0.5	0.4504 ± 0.003	0.5416 ± 0.0025
0.6	0.4405 ± 0.0027	0.5321 ± 0.002
0.7	0.4493 ± 0.0029	0.5223 ± 0.0022
0.8	0.4439 ± 0.0028	0.5213 ± 0.0022
0.9	0.4303 ± 0.0025	0.4987 ± 0.0019
1.0	0.4302 ± 0.0026	0.4972 ± 0.0017

82 3. Pairwise Analysis

83 We conducted pairwise sensitivity analysis for the behaviour response parameters λ and γ (Figure
84 2). In total, 81 combinations were used and results of each combination are given as the averages over
85 500 realizations. We find that increasing λ has the most beneficial effect on decreasing epidemic
86 final size and increasing vaccination rates. Also, increasing γ alongside λ can complement these
87 results decreasing incidence or increasing vaccination further. Increasing both of these parameters
88 can also decrease the NPI use amongst susceptible individuals at the end of an epidemic. This
89 seems counter intuitive, but since more individuals are vaccinating efficaciously and the amount of
90 infected individuals becomes smaller, many in the population do not need to practice strong NPI
91 use. However, increased γ with smaller values of λ can promote NPIs in the population, increasing
92 the use of these self protective measures when an epidemic is more widespread. Finally, an increase
93 in λ and γ will shorten the duration the an epidemic, given that far fewer people are becoming
94 infected.



(a)



(b)

Figure 2: Pairwise sensitivity analysis of parameters λ and γ . (a) cumulative incidence, (b) cumulative vaccination, (c) transmission rate reduction amongst susceptible population, (d) epidemic length. Results averaged over 500 trials.