Caution: Results are preliminary; please use along with other reports in this series and with caution.

Simulating Epidemic Outcomes under Different Re-opening and Testing Policies

Wan Yang, Sasikiran Kandula, Jeffrey Shaman (Columbia University)

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Purpose: To analyze potential COVID-19 epidemic outcomes in New York City under different re-opening/rollback policies along with active universal infection testing.

Timing of re-opening/rollback for three policies:

Phase	Policy 0	Policy 1	Policy 2
Phase 0	now – 6/8	now – 6/8	now – 6/8
Phase 1	6/8 – 7/8	adaptive	adaptive
Phase 2	7/8 – 12/31	adaptive	adaptive
Phase 3	not allowed	adaptive	adaptive
Phase 4	not allowed	adaptive	adaptive

Policy settings:

Policy 0: Fixed re-opening schedule as shown above

Policy 1: Adaptive re-opening/rollback, rollback one phase at a time.

Rules: If hospitalizations in the previous 2 weeks remain under threshold 1 (see below), open up 1 more phase (e.g. from Phase 1 this week to Phase 2 next week); if hospitalizations exceed threshold 1, rollback 1 phase (e.g. from Phase 2 this week to Phase 1 next week).

Policy 2: Adaptive re-opening/rollback, close all if at higher level of hospitalizations.

Rules: If hospitalizations in the previous 2 weeks remain under threshold 1, open up 1 more phase; if hospitalizations exceed threshold 1 but not threshold 2, rollback 1 phase; if hospitalizations exceed threshold 2, close all at once regardless of current phase.

Hospitalization thresholds:

Threshold 1: three consecutive days with COVID-like ED admissions above 200% of baseline ED pneumonia admissions as seen in prior years for corresponding period.

Threshold 2: three consecutive days with COVID-like ED admissions above 250% of baseline ED pneumonia admissions as seen in prior years for corresponding period.

Three Testing Strategies: (test capacity: 50 K per day)

Parameters	Strategy 0	Strategy 1	Strategy 2
Who to test	n/a	uhf(s) with the highest force of infection	uhfs with the highest force of infection
How to test	n/a	testing 1 person at a time	testing by household
Maximal # tests	0	250 K per round/week (50K tests per day x 5 days per round)	250 K per round/week (50K tests per day x 5 days per round
Maximal # person-tests	0	250 K per round	750 K per round (assume household size = 3)
Test sensitivity for the infectious (with high viral shedding)	n/a	95%	76% (assume 80% reduction due to batching)
Test sensitivity for the newly infected	n/a	60%	48% (assume 80% reduction due to batching)

For each policy, we simulate epidemic outcomes per the following settings:
1. Seasonality:
    1) Assume same seasonality as observed for OC43 (a beta-coronavirus, in the same genus as SARS-CoV-2).
    2) Assume no seasonality
2. Immunity: assumed ~3 years (range: 2.5 – 3.5 years); close to estimate for human endemic coronavirus combined (our estimate based on NYC data; unpublished)
3. Mobility: Estimated per categories of industries allowed to open in different phases (data from Safegraph.com)
    1) Low-level increase in mobility: Assume, initially, only 50% of industries open when allowed and those allowed in the previous phase open fully in the next phase.
    2) High-level increase in mobility: Assume 100% of industries open when allowed
4. Transmission rate/infectious period – representing level of infection control via precautionary measures (e.g. mask wearing, test & trace, disinfection, etc.). Of note, estimated transmission rate and infectious period decreased substantially from March 1 to May 30 (model training period), suggesting effectiveness of precautionary measures, in addition to reduction in mobility.
    1) Low-level increase in transmission rate/infectious period: 1st quartile
    2) Mid-level increase in transmission rate/infectious period: 2nd quartile
    3) High-level increase in transmission rate/infectious period: 3rd quartile
5. Re-introduction of infection (i.e. seeding) from outside:
    1) Low-level: 1 per 60 days per uhf
    2) Mid-level: 1 per 30 days per uhf
    3) High-level: 1 per 7 days per uhf

Note: to reduce number of combinations, we couple #4 with #5. For example, for simulations assuming a low-level increase in transmission rate/infectious period, the level of seeding is also assumed low. In total: 2 x 3 x 2 = 12 scenarios for each policy.

Modeling: A network SEIRS (susceptible-exposed-infectious-recovered-susceptible) model was trained on case and mortality data from the week of 3/1/20 to the week of 5/24/20. From the week of 5/31/20 to the week of 12/27/20, the model was integrated stochastically using state variables estimated for the most recent week (5/24) and corresponding parameter settings under each policy and scenario. Each simulation (500 ensemble members) was repeated 10 times and aggregated for the summary.

Some observations:

1) Impact of adaptive reopening/rollback:
    a. Comparing to fixed timing of reopening, both adaptive reopening/rollback policies would result in much lower number of infections, hospitalizations, and deaths. <u>Thus, active monitoring of epidemic indicators (e.g. hospitalizations) should be done and it is crucial to enact prompt public health interventions (i.e. rollback or closing) based on epidemic indicators. (see Figures 1-2 and Table 1)</u>
    b. Comparing to slower rollback (one phase at a time), more aggressive rollback (i.e. closing all at once) would result in much lower number of infections, hospitalizations, and deaths. This impact is more substantial when transmission rate is relatively high (20-35% reduction). Thus,

prompt and very aggressive interventions may be needed to prevent severe epidemic outcomes. (see Figures 1-2 and Table 1)

2) Impact of testing:
   a. In general, with additional active testing, there would be fewer infections, hospitalizations and deaths (1-15% reduction). (see Figures 3-4 and Table 2)
   b. With additional active testing, slightly longer/higher level of reopening would be enabled.
   c. Comparing testing one person at a time, testing by household would result in slightly fewer infections, hospitalizations and deaths (see Figures 3-4 and Table 2). However, this could be a result of longer/higher level of reopening enabled under testing strategy 1 (i.e. some active testing, test one person at a time). Therefore, the relative effectiveness of the two active testing strategies is inconclusive from these simulations.
   d. Note that with the current testing capacity, active universal testing of all citizens in NYC is impossible. To reflect current testing constraints, we simulated targeted testing of UHFs with the highest force of infection (i.e. highest number of infectious and newly infected as well as highest transmission rate). Even with such targeted testing, only 1-2 UHFs (out of 42 in total) if testing one person at a time, or 2-4 UHFs if testing by household could be tested. Thus, the impact of active universal testing may not be fully reflected at such a low testing coverage.

3) Under policy 2 (adaptive reopening/rollback, close all at once if high hospitalizations) and no active testing, and the "100% open, mid-tran" scenario, 16.9% (IQR: 2.3 – 39.2%) of the population would be infected and there would be 49.5 K (IQR: 7.0 K – 120.3 K) hospitalizations and 19.2 K (IQR: 2.7 K – 46.1 K) deaths tallied over 5/31 – 12/31/20.

Table 1. Comparing different **re-opening/rollback policies**. Summary results assuming 3-yr immunity and OC43 seasonality, including total infections (% population), total hospitalizations, and total deaths. Numbers are median (and interquartile range). Note that under the "50% open, low-tran" scenario, Policies 1-2 had higher %infections than Policy 0, because under those two policies, re-opening up to Phase 4 were allowed and adopted for a long period of time.

measure	scenario	Policy 0: Fixed, stop at Ph2	Policy 1: Rollback1by1	Policy 2: BackToPh0IfHigh
Infections (%)	50% open, low-tran	6.8 (0.8, 18)	8 (0.9, 23.3)	6.9 (0.6, 22.4)
Infections (%)	50% open, mid-tran	26.3 (6.5, 49)	21.7 (3.2, 45.7)	16.2 (1.7, 39.5)
Infections (%)	50% open, high-tran	49.3 (24.2, 66.4)	33.3 (8.7, 55)	23.3 (3.6, 45.5)
Infections (%)	100% open, low-tran	11 (3, 24.2)	11 (2.5, 26)	8.4 (1.4, 23.1)
Infections (%)	100% open, mid-tran	35.6 (12.5, 55.5)	26.2 (6.1, 48.7)	16.9 (2.3, 39.2)
Infections (%)	100% open, high-tran	55.6 (32.7, 70.7)	35.1 (10.9, 55.2)	26.4 (5.2, 47.7)
Hospitalizations	50% open, low-tran	19305 (2491, 54073)	22834 (2846, 69732)	20198 (2011, 66875)
Hospitalizations	50% open, mid-tran	75222 (18657, 153791)	61884 (9449, 139602)	47087 (5244, 120939)
Hospitalizations	50% open, high-tran	143713 (69099, 222186)	96515 (25491, 175584)	66976 (10378, 141606)
Hospitalizations	100% open, low-tran	31572 (8606, 74394)	31719 (7472, 79146)	24477 (4135, 70076)
Hospitalizations	100% open, mid-tran	102734 (35577, 179617)	76401 (18152, 151874)	49540 (7030, 120326)
Hospitalizations	100% open, high-tran	163367 (92471, 240815)	101240 (31194, 177825)	75758 (15278, 149370)
Deaths	50% open, low-tran	7732 (989, 21219)	8581 (1110, 25762)	7792 (894, 25150)
Deaths	50% open, mid-tran	29811 (7372, 58121)	23285 (3534, 51663)	18027 (1993, 46120)
Deaths	50% open, high-tran	58910 (27809, 81147)	38844 (9659, 66324)	26100 (3764, 53795)
Deaths	100% open, low-tran	12992 (3277, 28354)	12229 (2798, 29546)	9277 (1584, 26485)
Deaths	100% open, mid-tran	41234 (14082, 66973)	29255 (6661, 56418)	19196 (2660, 46050)
Deaths	100% open, high-tran	67066 (38406, 86613)	40155 (11643, 66212)	29922 (5786, 56504)

Table 2. Comparing different **testing strategies**. Summary results assuming 3-yr immunity and OC43 seasonality, including total infections (% population), total hospitalizations, and total deaths. Numbers are median (and interquartile range). Note that under the "100% open, high-tran" scenario, under policy 1 (adaptive, rollback one phase at a time), testing one person at a time had higher %infections than no testing; this is because, with this testing strategy, longer period/higher level of re-opening were enabled.

measure	scenario	Rollback 1 by 1, no test	Rollback 1 by 1, single test	Rollback 1 by 1, household test	Back to ph0 if high, no test	Back to ph0 if high, single test	Back to ph0 if high, household test
Infections (%)	50% open, mid-tran	21.7 (3.2, 45.7)	20.5 (2.7, 44.7)	19.3 (2.3, 43.9)	16.2 (1.7, 39.5)	15.9 (1.7, 39.2)	15.7 (1.5, 39.5)
Infections (%)	50% open, high-tran	33.3 (8.7, 55)	32.1 (7.9, 53.8)	30.9 (7.2, 52.7)	23.3 (3.6, 45.5)	23.1 (3.3, 45.8)	22.7 (3.2, 45.3)
Infections (%)	100% open, mid-tran	26.2 (6.1, 48.7)	24.7 (5.5, 47.1)	21.9 (4.3, 44.3)	16.9 (2.3, 39.2)	16.7 (2.3, 38.7)	16 (2.1, 38.3)
Infections (%)	100% open, high-tran	35.1 (10.9, 55.2)	36.6 (12.2, 56)	32.9 (9.4, 52.6)	26.4 (5.2, 47.7)	25.9 (4.9, 47.2)	24 (4.2, 45.7)
Hospitalizations	50% open, mid-tran	61884 (9449, 139602)	58886 (8189, 136267)	56148 (7038, 133848)	47087 (5244, 120939)	45862 (5022, 119604)	45241 (4547, 120025)
Hospitalizations	50% open, high-tran	96515 (25491, 175584)	93353 (23492, 172267)	90073 (21387, 168413)	66976 (10378, 141606)	67314 (9898, 143077)	65916 (9400, 140917)
Hospitalizations	100% open, mid-tran	76401 (18152, 151874)	71857 (15905, 146224)	64017 (12768, 137315)	49540 (7030, 120326)	48416 (6874, 118835)	46746 (6264, 117568)
Hospitalizations	100% open, high-tran	101240 (31194, 177825)	105320 (35227, 182082)	94596 (27306, 169179)	75758 (15278, 149370)	74229 (14366, 147850)	68957 (12173, 142286)
Deaths	50% open, mid-tran	23285 (3534, 51663)	22200 (3064, 50724)	21108 (2662, 50200)	18027 (1993, 46120)	17429 (1889, 45508)	17150 (1747, 45842)
Deaths	50% open, high-tran	38844 (9659, 66324)	37278 (8795, 64698)	36338 (8340, 63515)	26100 (3764, 53795)	26683 (3744, 54756)	25754 (3467, 53711)
Deaths	100% open, mid-tran	29255 (6661, 56418)	27257 (5789, 54429)	24271 (4594, 51437)	19196 (2660, 46050)	18667 (2556, 45357)	17943 (2347, 45009)
Deaths	100% open, high-tran	40155 (11643, 66212)	42205 (13628, 67438)	37311 (10384, 62333)	29922 (5786, 56504)	29279 (5445, 55925)	27161 (4641, 54135)

Fig 1. Comparing cumulative epidemic outcomes under *different **re-opening/rollback policies***. Boxplots show the distribution of simulated total number of infections (row 1), hospitalizations (row 2), or deaths (row 3), summed over the week of 5/31/20 – the week of 12/27/20). Three policies were tested: policy 0 - fixed timing, stop at Phase 2; policy 1 - adaptive, rollback one phase at a time; and policy 2 - adaptive, close all if higher hospitalizations. Each policy was simulated under 6 scenarios (labeled on the x-axis). Numbers in percentage indicate the relative changes compared to policy 0 (positive numbers indicate increases and negative indicate decreases). Columns show results under different *seasonality* assumptions (left: seasonality assumed; right: no seasonality)

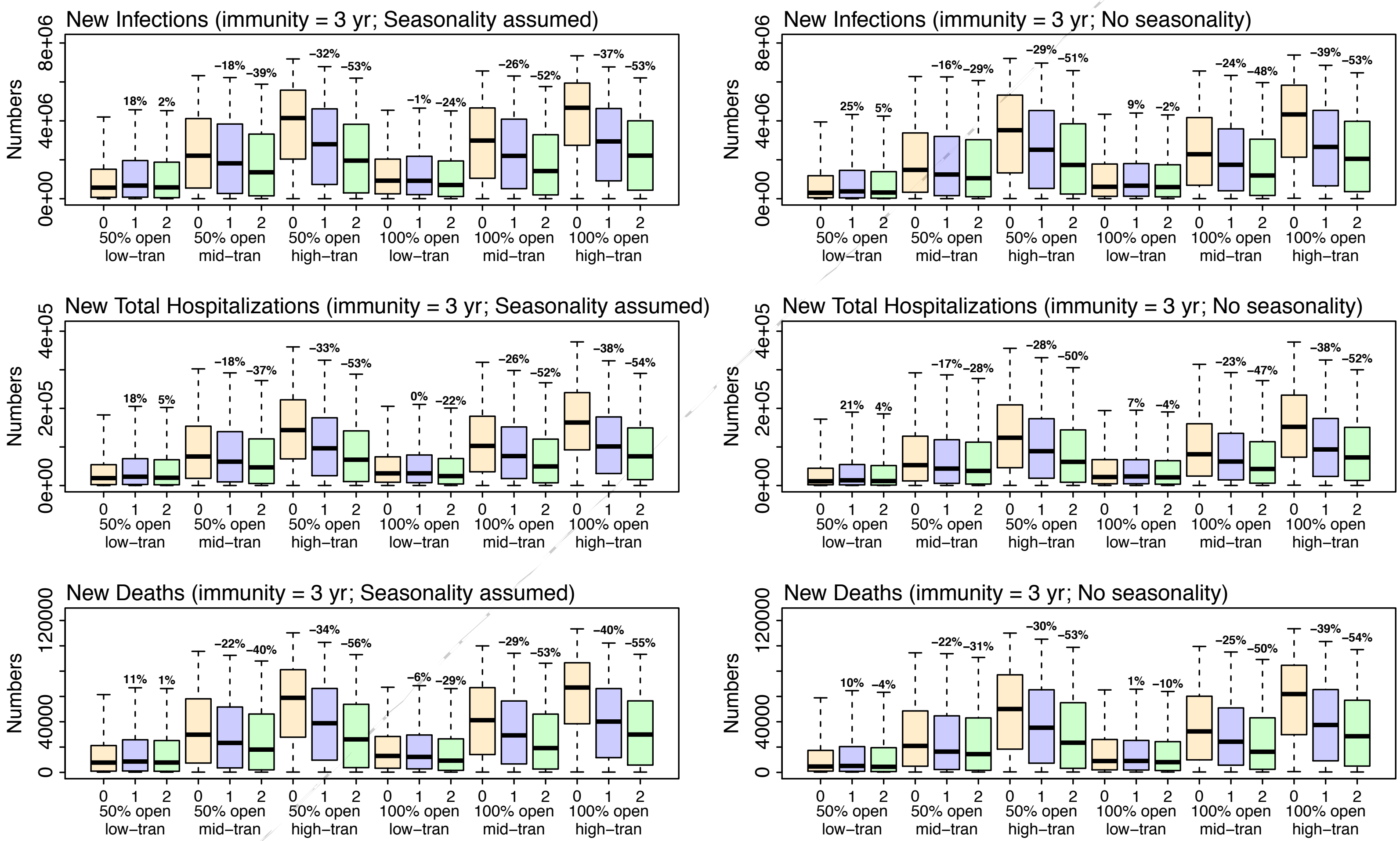

Fig 2. Comparing epidemic trajectories under different ***re-opening/rollback policies*** (# infections are shown here; for more epidemic outcomes, see other plots in pdf). Solid lines show median of simulated *weekly* number of infections. Policy option is indicated by color: Policy 0 (fixed timing, stop at phase 2) in orange, Policy 1 (adaptive, rollback one phase at a time) in blue, and Policy 2 (adaptive, close all if high hospitalizations) in green. Points with different shapes indicate the adopted phase for each week (□: all closed; o: phase 1; △: phase 2; +: phase 3; x: phase 4). Transmission scenarios are as labeled in the panel titles. Surrounding areas show the interquartile range. These simulations assumed 3-year immunity and human coronavirus OC43 seasonality for SARS-CoV-2.

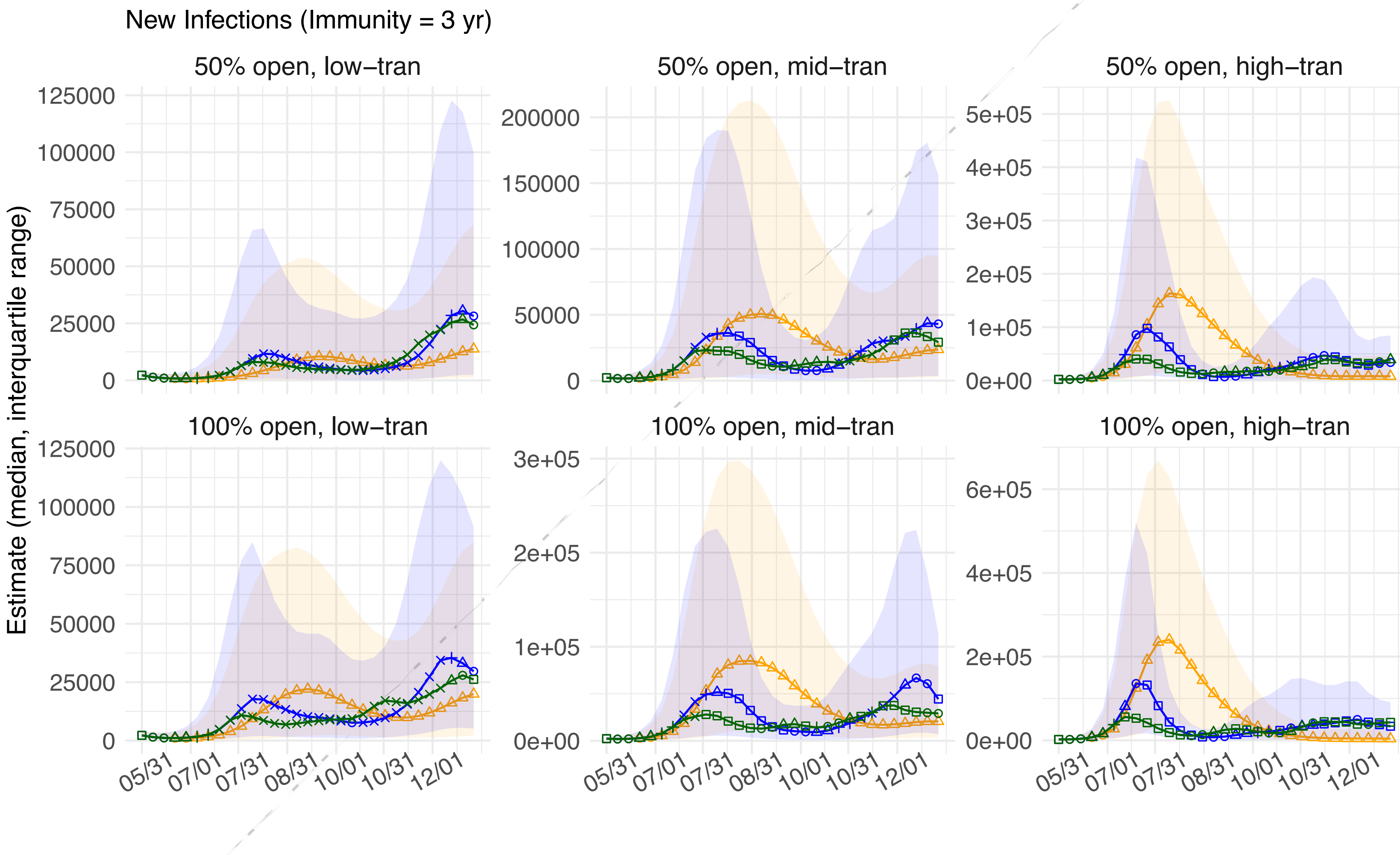

Fig 3. Comparing cumulative epidemic outcomes under *different* ***re-opening/rollback policies and testing strategies***. Boxplots show the distribution of simulated total number of infections (row 1), hospitalizations (row 2), or deaths (row 3), summed over the week of 5/31/20 – the week of 12/27/20). Two reopening policies in combination with three testing strategies were tested, as indicated in the x-axis (1st line: no = no testing; 1/1 = test one person at a time; hh = test by household; 2nd line: Rb1by1 = adaptive, rollback one phase at a time; RackToPh0 = adaptive, close all if high hospitalizations. Each policy/strategy was simulated under 4 scenarios (x-axis, 3rd line). Numbers in percentage indicate the relative changes compared to no testing at all for each policy/scenario (positive numbers indicate increases and negative indicate decreases). Columns show results under different *seasonality* assumptions (left: seasonality assumed; right: no seasonality)

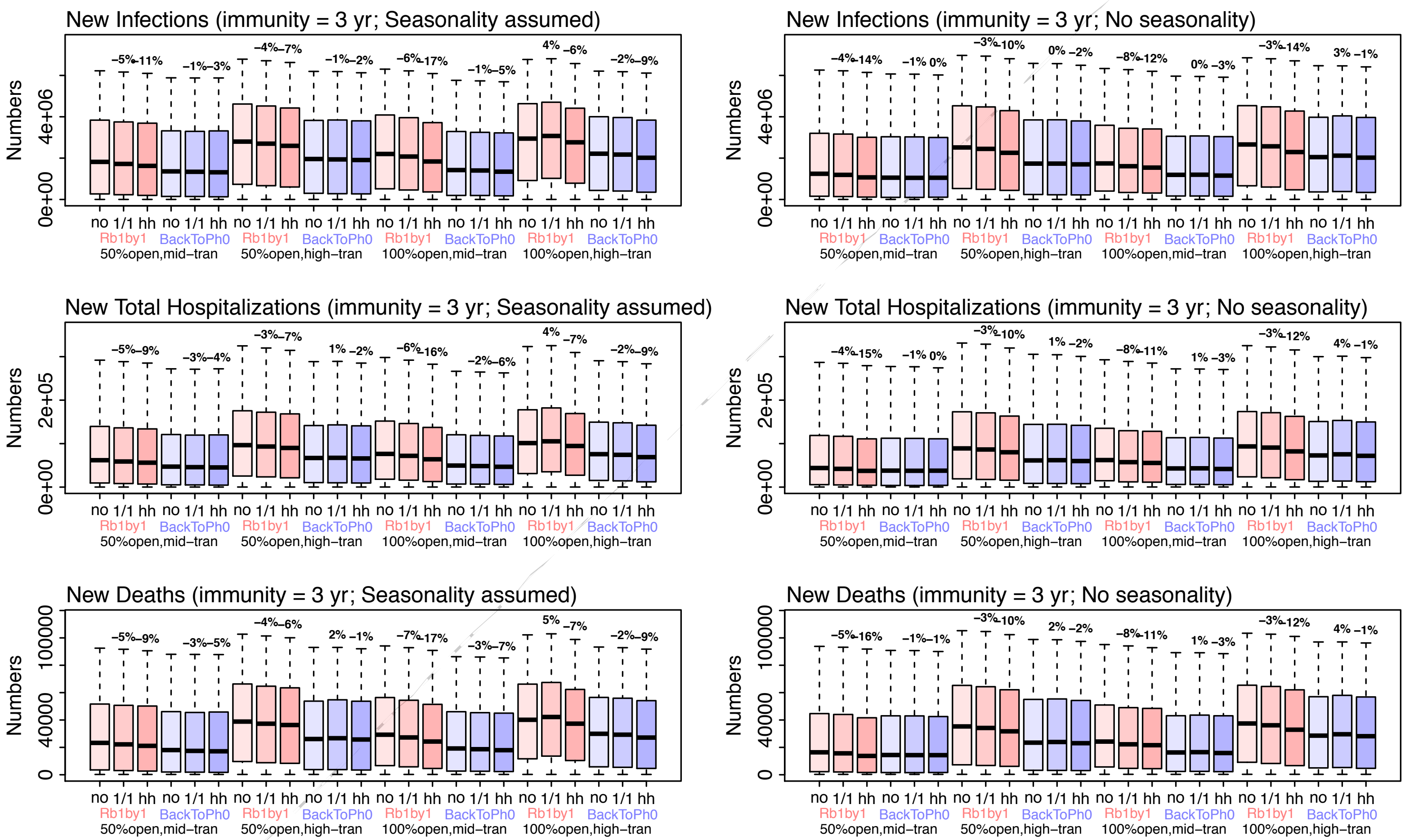

Fig 4. Comparing epidemic trajectories under different ***re-opening/rollback policies and testing strategies*** (# infections are shown here; for more epidemic outcomes, see other plots in pdf). Solid lines show median of simulated *weekly* number of infections. Warm colors show Policy 1 (adaptive, rollback one phase at a time): yellow = no test; orange = test one person at a time; red = test by household. Cold colors show Policy 2 (adaptive, close all if high hospitalizations): cyan = no test; blue = test one person at a time; purple = test by household. Points with different shapes indicate the adopted phase for each week (□: all closed; o: phase 1; △: phase 2; +: phase 3; x: phase 4). For clarity, the interquartile ranges are not shown here (for details see results in excel spreadsheets). Transmission scenarios are as labeled in the panel titles. These simulations assumed 3-year immunity and human coronavirus OC43 seasonality for SARS-CoV-2.