Simulating Epidemic Outcomes under Different Re-opening Policies

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

Document date: 5/26/2020

Purpose: To analyze potential COVID-19 epidemic outcomes in New York City for three policies with different re-opening schedules.

Three Policies:

Phase	Policy 1	Policy 2	Policy 3
Phase 0	now – 6/15	now – 7/1	now – 7/15
Phase 1	6/15 – 8/1	7/1 – 8/15	7/15 – 9/1
Phase 2	8/1 – 9/1	8/15 – 9/15	9/1 – 10/1
Phase 2	9/1 – 12/31	9/15 – 12/31	10/1 – 12/31

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:
   1) Short-term immunity: 1 year (range: 0.5 – 1.5 years)
   2) Mid-term immunity: 3 years (range: 2.5 – 3.5 years); close to estimate for human endemic coronavirus combined (our estimate based on NYC data; unpublished)
   3) Long-term immunity: 6 years (range: 5.5 – 6.5 years); close to estimate for OC43 (our estimate based on NYC data; unpublished) and reported for SARS-CoV-1 (2003 outbreak; Tang et al. 2011 *J Immunol* 186:7264-8)

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 23 (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 per age group
   2) Mid-level: 1 per 30 days per uhf per age group
   3) High-level: 1 per 7 days per uhf per age group

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 x 3 = 36 scenarios for each policy

Modeling: An age-specific, 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 5/17/20. From the week of 5/24/20 to the week of 12/27/20, the model was integrated stochastically using state variables estimated for the most recent week (5/17) 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 seasonality: There would be a large surge of infections entering November/ December, if SARS-CoV-2 followed similar seasonal pattern as human coronavirus OC43. (See Fig 1)
2) Impact of immunity: The magnitude of the epidemic would be larger for short-term than longer term immunity. (See Fig 2, comparing results in different rows)
3) The impact of delayed reopening:
   a. If transmission rate is kept at low levels:
      i) The benefit, e.g. relative decrease in infections and health outcomes (e.g. hospitalizations and deaths), would be larger if the transmission rate is kept at a low/medium level after reopening. (See Fig 2; comparing boxplots under different scenarios.)
      ii) This benefit would be larger if infection results in longer lasting immunity. (See Fig 2, comparing results in different rows)
   b. If transmission rate is high:
      i) There would be minimal or no benefit gained from delayed reopening if transmission rate is high. (See Fig 2; comparing boxplots under different scenarios.)
      ii) High transmission rate combining with winter seasonality could lead to detrimental outcomes from delayed reopening. This is likely because lower herd immunity built-up in the summer could result in higher susceptibility and a larger epidemic in the winter. (Fig 3)
4) Table 1 shows summary results assuming 3-yr immunity and OC43 seasonality, including total infections (% population), total hospitalizations, and total deaths, for the projected period. Under the scenario of 100% open and mid-transmission rate:
   a. Under Policy 1, 38.2% (IQR: 14.2 – 57.4%) of the population would be infected and there would be 95.1 K (IQR: 39.2 K – 169.4 K) hospitalizations and 34.6 K (IQR: 14.6 K – 60.5 K) deaths by the end of 2020.
   b. Under Policy 2, 38.8% (IQR: 13.3 – 58.6%) of the population would be infected and there would be 94.9 K (IQR: 37.4 K – 172.3 K) hospitalizations and 34.1 K (IQR: 13.8 K – 61.4 K) deaths by the end of 2020.
   c. Under Policy 3, 38.7% (IQR: 12.1 – 59.6%) of the population would be infected, and there would be 92.9 K (IQR: 34.5 K – 173.5 K) hospitalizations and 32.9 K (IQR: 12.6 K – 61.6 K) deaths by the end of 2020.

Overall, the order of outcome could change under different scenarios: Policy 1 is best in some scenarios and Policy 3 is best in others. This finding suggests that the variability is more modulated by mobility and transmission control in the community than policy.

Table 1. Summary results assuming 3-yr immunity and OC43 seasonality, including total infections (% population), total hospitalizations, and total deaths. Numbers are median (and interquartile range).

measure	scenario	Policy 1	Policy 2	Policy 3
Infections (%)	50% open, low-tran	9.2 (0.9, 30.2)	8.5 (0.7, 30.3)	7.4 (0.5, 30)
Infections (%)	50% open, mid-tran	30 (7.9, 52.5)	29.8 (7, 53.6)	28.9 (6, 54.5)
Infections (%)	50% open, high-tran	46.8 (22.7, 64.2)	47.8 (22.3, 65.2)	48.3 (21.5, 66.3)
Infections (%)	100% open, low-tran	17.1 (2.6, 36.8)	16.5 (2.2, 37.1)	15.4 (1.8, 37.1)
Infections (%)	100% open, mid-tran	38.2 (14.2, 57.4)	38.8 (13.3, 58.6)	38.7 (12.1, 59.6)
Infections (%)	100% open, high-tran	52.5 (30.2, 67.9)	53.7 (30.3, 68.9)	54.8 (29.9, 69.9)
Hospitalizations	50% open, low-tran	10410 (1731, 41290)	9180 (1545, 39353)	7896 (1385, 36892)
Hospitalizations	50% open, mid-tran	81389 (27993, 158015)	80051 (25793, 160244)	77049 (22982, 160679)
Hospitalizations	50% open, high-tran	156548 (89955, 231504)	160019 (91415, 236662)	162418 (91567, 241064)
Hospitalizations	100% open, low-tran	17405 (3034, 51225)	15896 (2556, 49074)	14130 (2153, 46568)
Hospitalizations	100% open, mid-tran	95114 (39219, 169410)	94869 (37442, 172372)	92894 (34487, 173525)
Hospitalizations	100% open, high-tran	165774 (100341, 239790)	169730 (102590, 245023)	172866 (103744, 249664)
Deaths	50% open, low-tran	2722 (843, 10595)	2392 (789, 9751)	2081 (731, 8822)
Deaths	50% open, mid-tran	29958 (10874, 57136)	29101 (9931, 57747)	27571 (8819, 57604)
Deaths	50% open, high-tran	62925 (38438, 83517)	64375 (38951, 85009)	65412 (38822, 86379)
Deaths	100% open, low-tran	4028 (1099, 13150)	3555 (985, 12138)	3084 (892, 11117)
Deaths	100% open, mid-tran	34657 (14612, 60484)	34144 (13778, 61362)	32866 (12562, 61567)
Deaths	100% open, high-tran	65758 (42290, 85560)	67304 (43222, 86990)	68544 (43554, 88307)

Fig 1. Comparing epidemic trajectories under models with vs. without seasonality. Solid lines show median of simulated *weekly* number of infections assuming human coronavirus OC43 seasonality; dashed lines show median of simulated number of infections assuming no seasonality. Policy option is indicated by color: Policy 1 in orange, Policy 2 in blue, and Policy 3 in green. Transmission scenarios are as labeled in the panel titles. Surrounding areas show the interquartile range.

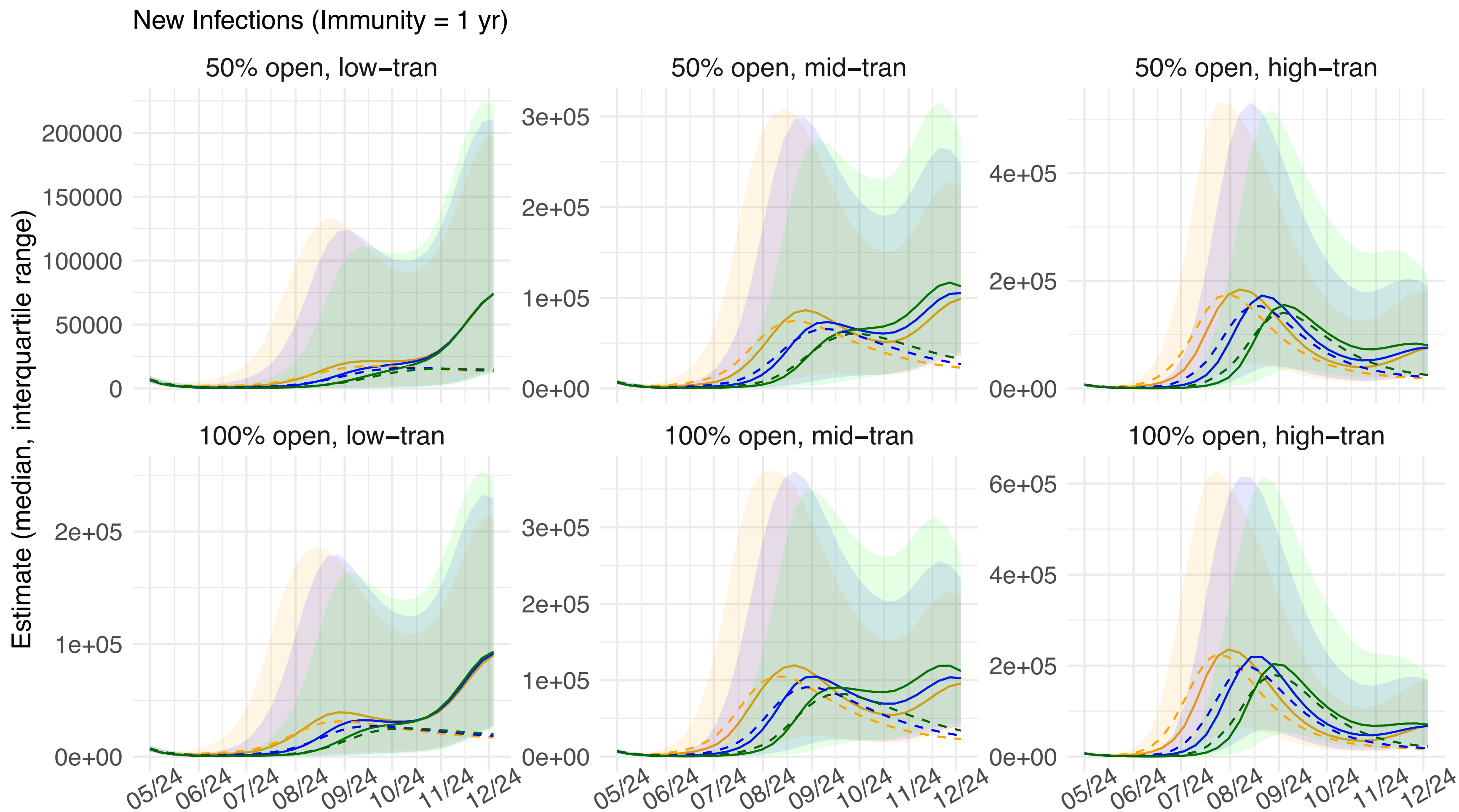

Fig 2. Comparing cumulative epidemic outcomes (number of infections shown here; see more outcomes in the pdf). Boxplots show the distribution of simulated total number of infections (summed over the week of 5/24/20 – the week of 12/27/20) under different policies (policy 1 in orange, policy 2 in blue, and policy 3 in green) and scenarios (labeled on the x-axis). Numbers in percentage indicate the relative changes compared to policy 1 (positive numbers indicate increases and negative indicate decreases). Rows show results under different *immunity* assumptions (top panel: 1 year; middle: 3 years; bottom: 6 years). Columns show results under different *seasonality* assumptions (left: seasonality assumed; right: no seasonality)

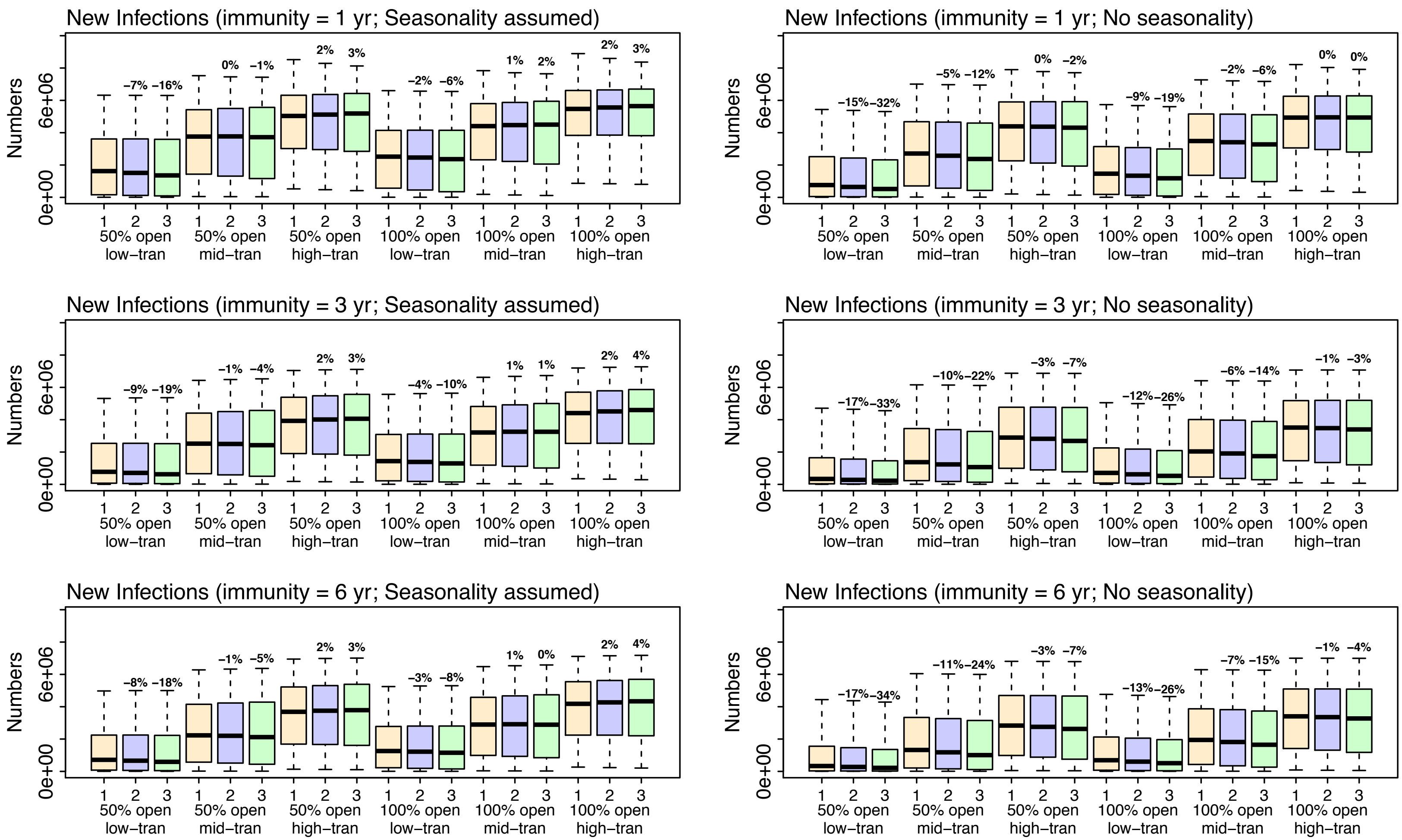

Fig 3. Comparing epidemic trajectories under different policies and transmission scenarios (number of infections are shown here; for more epidemic outcomes, see other plots in pdf). Solid lines show median of simulated *weekly* number of infections. Policy option is indicated by color: Policy 1 in orange, Policy 2 in blue, and Policy 3 in green. Transmission scenarios are as labeled in the panel titles. Surrounding areas show the interquartile range. These simulations assumed human coronavirus OC43 seasonality for SARS-CoV-2.

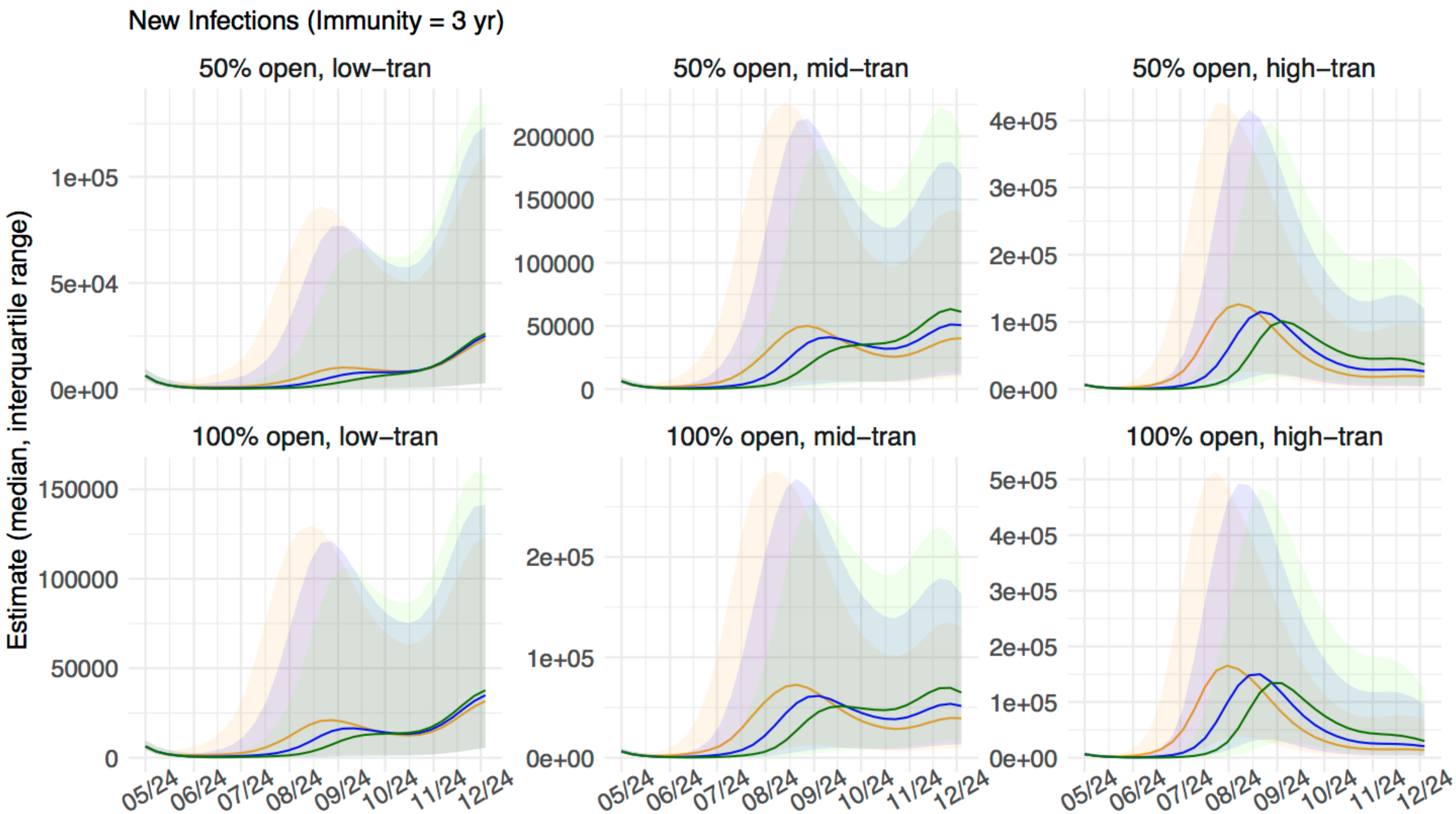

Fig 4. Same as Fig 3, but assumed no seasonality.