Supplemental Tables and Figures
for
Effectiveness of Non-pharmaceutical Interventions to Contain COVID-19:
A Case Study of the 2020 Spring Pandemic Wave in New York City
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Supplemental Tables

Table S1. Total number of reported cases and estimated cumulative infection rate by the
week of 5/31/20. Case rate was computed as the number of total cases divided by the
population size of the corresponding age group. Estimated infection rate was estimated by
model-inference system, normalized to the corresponding population size; numbers are
median (and 95% CrIs).

| Age | Total number of cases | Case rate (%) | Estimated infection rate (%) |
|-----|-----------------------|---------------|------------------------------|
| all | 205693 | 2.45 | 17.6 (13.2, 25.5) |
| <1 | 515 | 0.46 | 4.4 (2.9, 10.5) |
| 1-4 | 609 | 0.14 | 1.4 (0.9, 3.7) |
| 5-14 | 2646 | 0.28 | 10.5 (6.5, 24.5) |
| 15-24 | 12562 | 1.28 | 12.0 (8.4, 19.5) |
| 25-44 | 64764 | 2.45 | 22.7 (16.8, 31.5) |
| 45-64 | 74833 | 3.64 | 23.1 (18.4, 29.6) |
| 65-74 | 25469 | 3.64 | 15.2 (11.4, 21.7) |
| 75+ | 24295 | 4.44 | 12.7 (9.8, 18.4) |
### Table S2. Estimated reproductive number by week and age group. Numbers are median (and interquartile range) of the posterior estimates.

| date     | Age Groups | all  | <1   | 1-4  | 5-14 | 15-24 | 25-44 | 45-64 | 65-74 | 75+  |
|----------|------------|------|------|------|------|-------|-------|-------|-------|------|
| 3/1/20   | all        | 2.99 | 1.52 | 1.56 | 3.15 | 2.47  | 4     | 2.97  | 1.77  | 1.75 |
| 3/8/20   | all        | 2.25 | 1.43 | 1.28 | 2.35 | 2.02  | 2.46  | 2.49  | 1.98  | 1.84 |
| 3/15/20  | all        | 2.14 | 1.63 | 1.17 | 1.52 | 2.38  | 1.45  | 2.99  | 2.84  | 2.87 |
| 3/22/20  | all        | 1.37 | 1.59 | 1.17 | 0.99 | 1.29  | 0.76  | 1.37  | 2.58  | 2.52 |
| 3/29/20  | all        | 0.93 | 1.22 | 1.06 | 0.88 | 0.96  | 0.75  | 1.43  | 1.46  | 1.46 |
| 4/5/20   | all        | 0.63 | 0.74 | 0.84 | 0.53 | 0.77  | 0.44  | 0.62  | 0.9   | 0.9  |
| 4/12/20  | all        | 0.56 | 0.67 | 0.69 | 0.5  | 0.72  | 0.44  | 0.57  | 0.63  | 0.65 |
| 4/19/20  | all        | 0.59 | 0.68 | 0.68 | 0.57 | 0.81  | 0.55  | 0.49  | 0.6   | 0.66 |
| 4/26/20  | all        | 0.62 | 0.77 | 0.77 | 0.54 | 0.75  | 0.58  | 0.6   | 0.58  | 0.63 |
| 5/3/20   | all        | 0.66 | 0.78 | 0.78 | 0.56 | 0.72  | 0.68  | 0.68  | 0.58  | 0.63 |
| 5/10/20  | all        | 0.82 | 0.71 | 0.75 | 0.6  | 0.88  | 0.55  | 0.73  | 0.73  | 0.65 |
| 5/17/20  | all        | 1.03 | 0.82 | 0.82 | 0.73 | 1.1   | 1.21  | 1.1   | 1.04  | 1.04 |
| 5/24/20  | all        | 0.89 | 0.78 | 0.79 | 0.69 | 0.94  | 0.96  | 0.95  | 0.79  | 0.89 |
| 5/31/20  | all        | 0.79 | 0.71 | 0.71 | 0.71 | 0.85  | 0.79  | 0.77  | 0.72  | 1.04 |
**Table S3.** Correlation of key epidemiological parameters with population mobility during the week of March 1 – the week of May 31, 2020.

| Age  | Rt (ignore susceptibility) | Transmission rate | Infectious period |
|------|----------------------------|-------------------|-------------------|
| all  | 0.96                       | 0.96              | 0.73              | 0.54              |
| <1   | 0.76                       | 0.77              | 0.41              | 0.70              |
| 1-4  | 0.93                       | 0.93              | 0.05              | 0.65              |
| 5-14 | 0.99                       | 0.99              | 0.86              | 0.92              |
| 15-24| 0.90                       | 0.91              | 0.52              | -0.05             |
| 25-44| 0.93                       | 0.96              | 0.80              | 0.27              |
| 45-64| 0.88                       | 0.90              | 0.60              | 0.24              |
| 65-74| 0.57                       | 0.63              | 0.54              | 0.65              |
| 75+  | 0.55                       | 0.60              | 0.50              | 0.64              |
**Table S4.** Prior ranges for main model parameters and variables. The spatial, temporal, and age resolution of each parameter or variable, estimated in the model-inference system, is specified in the column "Resolution". Note posterior parameter estimates can extend outside the specified prior ranges. Note this is the same as Table S1 in Yang et al. (1)

| Parameter/variable | Symbol | Resolution | Prior range | Source/rationale |
|--------------------|--------|------------|-------------|------------------|
| Initial exposed    | E(t=0) | neighborhood- and age-group specific, estimated for the beginning of the Week of March 1, 2020 | 300 – 8000 total citywide, scaled by population size for each age group and neighborhood | Large uncertainties, used very wide range |
| Initial infectious  | I(t=0) | neighborhood- and age-group specific, estimated for the beginning of the Week of March 1, 2020 | 150 – 4000 total citywide, scaled by population size for each age group and neighborhood | Assumed to be half the initial exposed |
| Initial susceptible | S(t=0) | neighborhood- and age-group specific, estimated for the beginning of the Week of March 1, 2020 | N – E – I | Assumed all were susceptible except for those initially exposed/infectious |
| Population size in each age group and neighborhood | N | neighborhood- and age-group specific | N/A | NYC intercensal population estimates for 2018(2) |
| Citywide transmission rate | β_city | Citywide, age-group specific, estimated for each week | [0.5, 1] per day overall; scaled by contact rate for each age group based on contact data from the POLYMOD study(3) (averaged across 8 countries) | Based on R₀ estimates of around 1.5-4 for SARS-CoV-2(4-6) |
| Scaling of neighborhood transmission rate | b_i | neighborhood- and age-group specific, estimated for each week | [0.8, 1.2] for age groups under 65 years; [0.5, 1.5] for age groups 65 or older | Around 1; larger variation for elderly groups based on data |
| Parameter                          | Description                                                                 | Citywide, age-group specific, estimated for each week | Citywide, age-group specific, estimated for each week |
|-----------------------------------|-----------------------------------------------------------------------------|-------------------------------------------------------|-------------------------------------------------------|
| Latency period                    | Z                                                                           | [2, 5] days                                          | [2, 5] days                                          |
| Incubation period: 5.2 days       | (95% CI: 4.1, 7)                                                          | latency period is likely shorter than the incubation period |
| Infectious period                 | D                                                                           | [2, 5] days                                          | [2, 5] days                                          |
| Time from symptom onset to hospitalization: 3.8 days | (95% CI: 0, 12.0) in China,(7) plus 1-2 days viral shedding before symptom onset. We did not distinguish symptomatic/asymptomatic infections. |
| Multiplicative factor for mobility | $m_1$                                                                      | [1, 2] for <1 year; [0.5, 1.5] for three age groups 1-24 years; [0.1, 1.5] for age group 25-44; [1, 2.5] for age groups 45 or older | [0.5, 2] |
| Initial model testing showed transmission rates for younger age groups were more sensitive to changes in mobility whereas the two oldest age groups were not sensitive to mobility. For age groups with contact rates lower than the average (based on the POLYMOD study(3)), we raised the diagonal elements in the mobility matrix to the power of the relative contact rate (<1) to account for insensitivity of transmission rate in these age groups to mobility. |
| Multiplicative factor for neighborhood connectivity | $m_2$                                                                      | [0.5, 2] |
| Likely around 1 but with large uncertainties |
| Mean of time from viral shedding to diagnosis | $T_m$                                                                      | [3, 8] days                                          | [3, 8] days                                          |
| From a few days to a week from symptom onset to diagnosis/reporting,(7) plus 1-2 days of viral shedding (being infectious) before symptom onset |
Standard deviation (SD) of time from viral shedding to diagnosis

\( T_{sd} \)

Citywide, age-group specific, estimated for each week [1, 3] days

To allow variation in time to diagnosis/reporting

Reporting rate \( r \)

Citywide, age-group specific, estimated for each week

Starting from \([0.001, 0.05]\) at time 0 and allowed to increase over time using space re-probing (8)

Infection fatality risk (IFR)

Citywide, age-group specific, estimated for each week

\([5, 15] \times 10^{-5}\) for ages under 25; \([5, 15] \times 10^{-4}\) for ages 25-44; \([5, 15] \times 10^{-3}\) for ages 45-64; \([0.01, 0.1]\) for ages 65-74; \([0.02, 0.2]\) for ages 75+;

Large uncertainties

Time from diagnosis to death

Citywide

Gamma distribution with mean of 9.36 days and SD of 9.76 days

Based on \( n=15,686 \) COVID-19 confirmed deaths in NYC as of May 17, 2020.

Reference:
1. W. Yang, S. Kandula, M. Huynh, S. K. Greene, G. Van Wye, W. Li, H. T. Chan, E. McGibbon, A. Yeung, D. Olson, A. Fine, J. Shaman, Estimating the infection fatality risk of COVID-19 in New York City, March 1-May 16, 2020. medRxiv, 2020.2006.2027.20141689 (2020).
2. New York City Department of Health and Mental Hygiene.
3. J. Mossong, N. Hens, M. Jit, P. Beutels, K. Auranen, R. Mikolajczyk, M. Massari, S. Salmaso, G. S. Tomba, J. Wallinga, J. Heijne, M. Sadkowska-Todys, M. Rosinska, W. J. Edmunds, Social contacts and mixing patterns relevant to the spread of infectious diseases. PLoS Med 5, e74 (2008).
4. Q. Li, X. Guan, P. Wu, X. Wang, L. Zhou, Y. Tong, R. Ren, K. S. M. Leung, E. H. Y. Lau, J. Y. Wong, X. Xing, N. Xiang, Y. Wu, C. Li, Q. Chen, D. Li, T. Liu, J. Zhao, M. Liu, W. Tu, C. Chen, L. Jin, R. Yang, Q. Wang, S. Zhou, R. Wang, H. Liu, Y. Luo, Y. Liu, G. Shao, H. Li, Z. Tao, Y. Yang, Z. Deng, B. Liu, Z. Ma, Y. Zhang, G. Shi, T. T. Y. Lam, J. T. Wu, G. F. Gao, B. J. Cowling, B. Yang, G. M. Leung, Z. Feng, Early Transmission Dynamics in Wuhan, China, of Novel Coronavirus–Infected Pneumonia. New Engl J Med, (2020).
5. J. T. Wu, K. Leung, G. M. Leung, Nowcasting and forecasting the potential domestic and international spread of the 2019-nCoV outbreak originating in Wuhan, China: a modelling study. Lancet, (2020).
6. R. Li, S. Pei, B. Chen, Y. Song, T. Zhang, W. Yang, J. Shaman, Substantial undocumented infection facilitates the rapid dissemination of novel coronavirus (SARS-CoV-2). Science 368, 489-493 (2020).
7. J. Zhang, M. Litvinova, W. Wang, Y. Wang, X. Deng, X. Chen, M. Li, W. Zheng, L. Yi, X. Chen, Q. Wu, Y. Liang, X. Wang, J. Yang, K. Sun, I. M. Longini, Jr., M. E. Halloran, P. Wu, B. J. Cowling, S. Merler, C. Viboud, A. Vespignani, M. Ajelli, H. Yu, Evolving epidemiology and transmission dynamics of coronavirus disease 2019 outside Hubei province, China: a descriptive and modelling study. The Lancet. Infectious diseases, (2020).

8. W. Yang, J. Shaman, A simple modification for improving inference of non-linear dynamical systems. arXiv, 1403.6804 (2014).

9. R. Verity, L. C. Okell, I. Dorigatti, P. Winskill, C. Whittaker, N. Imai, G. Cuomo-Dannenburg, H. Thompson, P. G. T. Walker, H. Fu, A. Dighe, J. T. Griffin, M. Baguelin, S. Bhatia, A. Boonyasiri, A. Cori, Z. Cucunuba, R. FitzJohn, K. Gaythorpe, W. Green, A. Hamlet, W. Hinsley, D. Laydon, G. Nedjati-Gilani, S. Riley, S. van Elsland, E. Volz, H. Wang, Y. Wang, X. Xi, C. A. Donnelly, A. C. Ghani, N. M. Ferguson, Estimates of the severity of coronavirus disease 2019: a model-based analysis. The Lancet. Infectious diseases, (2020).
Supplemental Figures

**Fig S1.** Model fits of reported confirmed COVID-19 cases. Blue dots show reported number of cases by age group and week of diagnosis. Boxes show the model fitted weekly number of cases by age group. Box edges, thick middle lines, and whiskers show the 2.5th, 25th, 50th, 75th, and 97.5th percentiles of model estimates.
**Fig S2.** Model fits of reported COVID-19 associated deaths. Blue dots show reported weekly number of deaths by age group. Boxes show the model fitted weekly number of deaths by age group. Box edges, thick middle lines, and whiskers show the 2.5\(^{th}\), 25\(^{th}\), 50\(^{th}\), 75\(^{th}\), and 97.5\(^{th}\) percentiles of model estimates. Note that deaths among <25 year-olds are combined due to low counts.
**Fig S3.** Estimated case rates and infection rates by age group. Blue dots show confirmed case rates by age group and week of diagnosis. Blue boxes (left y-axis) show the model fitted weekly case rates and grey boxes (right y-axis) show the model estimated weekly infection rates by age group. Box edges, thick middle lines, and whiskers show the 2.5th, 25th, 50th, 75th, and 97.5th percentiles of model estimates.
**Fig S4.** Sensitivity analysis on the effectiveness of reducing contact rate by neighborhood. There are 42 United Hospital Fund (UHF) neighborhoods in NYC. (A) shows the changes in human mobility during the pandemic by neighborhood (each colored line). The reductions were substantial in all neighborhoods but to varying degrees. (B) shows the estimated $R_t$ (combining all ages) for each week and neighborhood (each colored line). Note these estimates did not account for changes in susceptibility so as to restrict to changes due to interventions. (C) shows the adjusted $r^2$ of linear regression model fitting the mobility data (A) to the $R_t$ estimates (B), for each neighborhood, per Eqn 2 in the main text. Adjusted $r^2$ for most neighborhoods was >0.9. (D) shows the estimated reduction in $R_t$ by the Week of April 12, 2020 based on the Eqn 3 in the main text, for each neighborhood. The histogram is based on the median estimated reduction in $R_t$. 

![Graph A: Changes in mobility (relative to the Week of 3/1/2020)](image1)

![Graph B: Rt estimates from the model–inference system](image2)

![Graph C: Model–fit by neighborhood: Adjusted $r^2$](image3)

![Graph D: Estimated reduction in neighborhood–specific Rt by the Week of April 12, 2020 (based on the median)](image4)
**Fig S5.** Projections of COVID-19 cases by age group eight weeks beyond the study period. Blue dots show observed confirmed cases by week of diagnosis (those after the Week of 5/31/2020 were not used in the model). Blue lines show model median estimates; surrounding shades show 50% and 90% CrIs. Orange lines show model projected median weekly cases and deaths; surrounding shades show 50% and 90% CIs of the projection.
**Fig S6.** Projections of COVID-19 associated deaths by age group eight weeks beyond the study period. Blue dots show observed weekly deaths (those after the Week of 5/31/2020 were not used in the model). Blue lines show model median estimates; surrounding shades show 50% and 90% CrIs. Orange lines show model projected median weekly cases and deaths; surrounding shades show 50% and 90% CIs of the projection.

(A) all  
(B) <25 year-olds  
(C) 25–44 year-olds  
(D) 45–64 year-olds  
(E) 65–74 year-olds  
(F) 75+ year-olds

Number per Week

Week Start
**Fig S7.** Comparing long term projection with available observations. The projections on COVID-19 cases, hospitalizations and deaths were generated on June 30, 2020, using case and mortality data up to June 26, 2020. These projections were generated at the time using a simpler model without age grouping but otherwise the same methodology presented in the study. Results were posted online on June 30, 2020 (https://github.com/wan-yang/re-opening_analysis/tree/master/test3_occupancy). Various policy scenarios were tested and here we used the one labeled “sce2fix_asIs” for the “intervention” identifier, which has been the closest to implemented interventions thus far (main settings were capping capacity for all industries including schools at 50%; no shutdown). For comparison with observations thus far, we used data published by the New York City Department of Health and Mental Hygiene, as of Dec 27, 2020 (https://raw.githubusercontent.com/nychealth/coronavirus-data/master/trends/data-by-day.csv). Red line and shaded area show our projections (median and interquartile range) and blue dots show corresponding observations from the New York City Department of Health and Mental Hygiene. Note that estimated infection-detection rates using PCR tests during June – Dec 2020 have been similar to those in June. However, hospitalization rates and estimated infection-fatality-risk in months after June 2020 have been lower than that during the spring wave; these lower hospitalization rates and mortality risks contribute to the lower observed numbers than our projections.