Reductions in commuting mobility predict geographic differences in SARS-CoV-2 prevalence in New York City

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Abstract.

Importance: New York City is the epicenter of the SARS-CoV-2 pandemic in the United States. Mortality and hospitalizations have differed substantially between different neighborhoods. Mitigation efforts in the coming months will require knowing the extent of geographic variation in SARS-CoV-2 prevalence and understanding the drivers of these differences.

Objective: To estimate the prevalence of SARS-CoV-2 infection by New York City borough between March 22nd and May 3rd, 2020, and to associate variation in prevalence with antecedent reductions in mobility, defined as aggregated daily physical movements into and out of each borough.

Design: Observational study of universal SARS-CoV-2 test results obtained from women hospitalized for delivery.

Setting: Four New York-Presbyterian hospital campuses and two Mount Sinai hospital campuses in New York City.

Participants: 1,746 women with New York City ZIP codes hospitalized for delivery.

Exposures: Infection with SARS-CoV-2.

Main outcomes: Population prevalence of SARS-CoV-2 by borough and correlation with the reduction in daily commuting-style movements into and out of each borough.

Results: The estimated population prevalence of SARS-CoV-2 ranged from 11.3% (95% credible interval 8.9%, 13.9%) in Manhattan to 26.0% (95% credible interval 15.3%, 38.9%) in South Queens, with an estimated city-wide prevalence of 15.6% (95% credible interval 13.9%, 17.4%). The peak city-wide prevalence was during the week of March 30th, though temporal trends in prevalence varied substantially between boroughs. Population prevalence was lowest in boroughs with the greatest reductions in morning commutes out of and evening commutes into the borough (Pearson $R = -0.88$, 95% credible interval –0.52, –0.99).

Conclusions and relevance: Reductions in between-borough mobility predict geographic differences in the prevalence of SARS-CoV-2 infection in New York City. Large parts of the city may remain at risk for substantial SARS-CoV-2 outbreaks. Widespread testing should be conducted to identify geographic disparities in prevalence and assess the risk of future outbreaks.

Main text.

Pronounced geographic differences in hospitalization and mortality rates have emerged as a hallmark of the ongoing SARS-CoV-2 pandemic. In New York City, the epicenter of the SARS-CoV-2 epidemic in the United States, deaths and hospitalizations *per capita* due to COVID-19 were nearly twice as high in the Bronx as in neighboring Manhattan as of April 25th 2020.[1] To the extent that this variation reflects the cumulative incidence of SARS-CoV-2 infections, there may be wide disparities in exposure to the novel coronavirus across New York City. Furthermore, if exposure leads to protection from re-infection, substantial levels of immunity may have already accrued in some areas of the city, while other neighborhoods may still be susceptible to a major outbreak. Understanding this risk landscape is key for informing plans to responsibly resume commerce in the coming months.

The local prevalence of SARS-CoV-2 infection depends on a number of factors, including the patterns of contacts among people within and between communities. Physical distancing interventions, including the "New York State on PAUSE" executive order starting March 22nd,[2] have dramatically changed the behaviors that drive these contacts. COVID-19 hospitalization and mortality rates are an imperfect proxy of prevalence, since these measures also depend on access to care, age, social determinants of health, and the rates of underlying medical conditions as well as non-disease-related phenomena such as hospital overload. Measuring the prevalence of SARS-CoV-2 infection has been difficult because tests are generally only administered for patients with presumed COVID-19 illness, leaving mild, asymptomatic, and pre-symptomatic cases uncounted. Imperfect test sensitivity adds an additional layer of complexity to extrapolating the results of SARS-CoV-2 tests to the general population.

To estimate SARS-CoV-2 prevalence by New York City borough, we analyzed SARS-CoV-2 test results administered universally to 2,011 pregnant women admitted for delivery at four New-York Presbyterian hospital campuses (Columbia University Irving Medical Center/NYP-CUIMC, Weill Cornell Medical Center/NYP-WCM, Lower Manhattan Hospital/NYP-LMH, and Queens Hospital/NYP-Queens), Mount Sinai Hospital (MSH), and Mount Sinai West (MSW) hospital between March 22nd and May 3rd, 2020. NYP-CUIMC tests included those from NYP-Morgan Stanley Children's Hospital and NYP-Allen Hospital. We excluded tests from women with a ZIP code outside of New York City (n = 251) or in Staten Island (n = 14) due to the small sample size from that borough, leaving tests from 1,746 women (**Table 1**). Consistent with a recent report,[3] 244 (14.0%) of the women tested positive for SARS-CoV-2. Of these, 55 (22.5%) reported symptoms including fever, cough, sore throat, chills, malaise, chest pain, shortness of breath, anosmia, or hyposmia. We combined these data with high-volume mobility data[4] from Facebook users capturing the number of daily trips made into and out of each borough to assess how changes in individuals' movement patterns may have contributed to geographic variation in SARS-CoV-2 prevalence.

Each SARS-CoV-2 test record was assigned to a borough on the basis of the 3-digit prefix of the patient's ZIP code (**Supplemental Table 1**).[5] To improve the spatial resolution, we separated Queens, the largest borough by land area, into North and South regions, delineated by the New York State Department of Health's neighborhood designations of North/Northeast/Northwest/West/West Central/Central and Jamaica/Rockaways/Southeast/Southwest, respectively (**Supplemental Table 1**).[5] The percentage of tests positive for SARS-CoV-2 ranged from 10.0% (72/718) in Manhattan to 22.4% (13/58) in South Queens (**Supplemental Table 2**). We used a statistical framework[6,7] to estimate the population prevalence of SARS-CoV-2 infection by borough accounting for imperfect test sensitivity, which has been reported as low as 70%[8] (**Figure 1A, Supplemental Table 3**). Conservatively estimating a test sensitivity of 90%, the mean estimated population prevalence of SARS-CoV-2 infection in Manhattan (11.3%, 95% credible interval (CI) [8.9%, 13.9%]) was substantially lower than in the Bronx (20.8%, [16.2%, 25.7%]) and South Queens (26.0%, [15.3%, 38.9%]) during the study period. Differences were not affected by assumed 80% and 70% sensitivity (**Supplemental Table 3**). Estimating the mean prevalence of SARS-CoV-2 infection in New York City using the data aggregated across all boroughs (15.6%, [13.9%, 17.4%]; **Figure 1A,** black line) would mask these substantial geographic differences. The estimated prevalence of infection remained roughly constant over time (**Figure 1B**) within statistical uncertainty, though the trends suggest that prevalence in the city as a whole rose until the week of March 30th and has since tapered and leveled.

To assess the possible relationship between variable reductions in between-borough movements and the subsequent prevalence of infection, we used mobility data provided by Facebook's Data for Good program.[4] The data represent approximately 1 million Facebook users in the New York City area who have location services enabled on their mobile device. The data provide 8-hour snapshots of the number of transitions that occurred between ~1.2km^2 patches in New York City. A transition is defined as a directional vector starting at the location where an individual spent the majority of their time during the preceding 8-hour window of time and ending at the location where the same individual spent a majority of their time during the current 8-hour window of time. We aggregated these data by borough and time of day (morning *vs.* evening, or 4am-12pm *vs.* 12pm-8pm) and calculated the number of morning transitions out of each borough and evening transitions into each borough during the study period to approximate work-related commuting. We compared these values to the number of analogous transitions that occurred during the 45-day period preceding February 26th, 2020, conditional on the day of the week and time of day. We chose to assess commuting between boroughs as opposed to within-borough movements because movements within a borough or neighborhood could include a variety of activities consistent with social distancing, whereas commuting between boroughs is likely to be associated with work and is therefore likely to be a good indicator of an inability to engage in social distancing. The magnitude of the reduction in commuting movements between boroughs ranged from 41.4% in South Queens to 68.7% in Manhattan (**Supplemental Table 4**). The mean estimated prevalence of SARS-CoV-2 infection by borough was strongly inversely correlated with the reduction in commuting movements (Pearson $R = -0.88$, [–0.52, –0.99]) in each borough (**Figure 2**).

The prevalence of SARS-CoV-2 infection between March 22nd and May 3rd, 2020 differed substantially between New York City boroughs and was related to reductions in daytime commuting-style movements into and out of each borough relative to the previous two months. The estimated prevalence in Manhattan was substantially lower than in Queens and the Bronx, consistent with geographic differences in cumulative hospitalizations and mortality.[1] The variations in mobility across neighborhoods likely depended on factors including the distribution of essential workers and of resources to support distancing. If the differences in prevalence correlate with differences in population immunity, Manhattan may remain at higher risk of a major resurgence than the other boroughs as social distancing measures are relaxed, particularly when people who have left the city during the lockdown return.

Our findings are subject to a number of limitations. Women hospitalized for delivery may not be representative of the population.[9,10] Pregnancy may also dampen the immune response to the virus,[11] possibly leading to a different duration of infection and therefore a biased representation of SARS-CoV-2 infection in pregnant women *vs.* the rest of the population. We have used mobility data as a proxy for physical distancing, but the mobility data do not perfectly capture the interpersonal contacts that underlie the transmission of SARS-CoV-2, nor do they necessarily capture the demographics of the women tested here for SARS-CoV-2. A direct causal link between physical distancing and the reduction in transmission cannot be drawn, because the ability to physically distance may also be related to age, income, type of employment, type of housing, and other factors that could independently modulate risk of infection. In addition, just as the prevalence of infection in the boroughs is more heterogeneous than the aggregate prevalence across New York City would suggest, there may be substantial geographic heterogeneity in prevalence within boroughs that is not captured in our study.

In conclusion, mobility patterns consistent with commuting predict the prevalence of SARS-CoV-2 infection in New York City boroughs. Large parts of the city may remain at risk for substantial SARS-CoV-2 outbreaks. These results highlight the need to provide greater support to neighborhoods unable to comply with social distancing interventions and that widespread SARS-CoV-2 testing remains key for assessing geographic disparities in infection prevalence, allowing for more tailored interventions and a better assessment of the risk of additional outbreaks.

Acknowledgements. We thank Matthew Sisson for assistance with data collection. The work was supported in part by the Morris-Singer Fund for the Center for Communicable Disease Dynamics at the Harvard T.H. Chan School of Public Health. The funding source had no role in study design; in the collection, analysis, and interpretation of data; in the writing of the report; and in the decision to submit the paper for publication.

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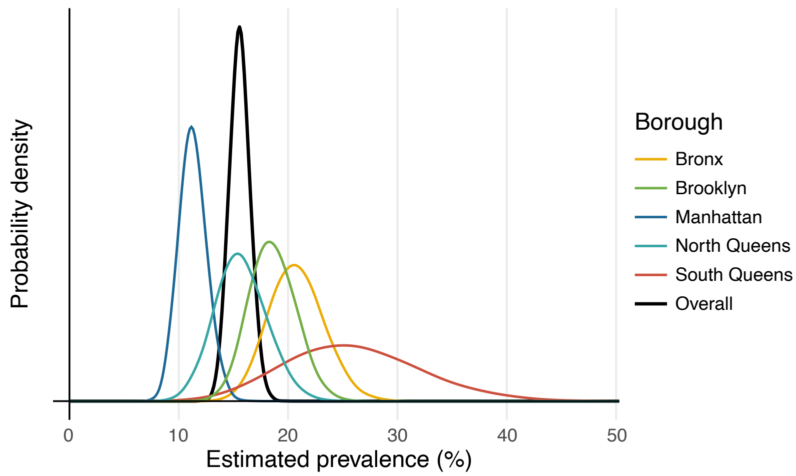
Category	*N*	%
Total	1,746	100
Site		
NYP-CUIMC	385	22.1
NYP-LMH	137	7.9
NYP-Queens	178	10.2
NYP-WCM	290	16.6
MSH	428	24.5
MSW	328	18.8
SARS-CoV-2 test result		
Positive	244	14.0
Negative	1,502	86.0
Borough		
Bronx	309	17.7
Brooklyn	386	22.1
Manhattan	718	41.1
North Queens	275	15.8
South Queens	58	3.3
Age		
15-19	21	1.2
20-24	167	9.6
25-29	346	19.8
30-34	588	33.7
35-39	470	26.9
40-44	139	8.0
45-49	13	0.7
50-54	2	0.1

Table 1. Characteristics of the study population. Abbreviations: New York Presbyterian Columbia University Irving Medical Center (NYP-CUIMC), Weill Cornell Medical Center (NYP-WCM), Lower Manhattan Hospital (NYP-LMH), and Queens Hospital (NYP-Queens), Mount Sinai Hospital (MSH), and Mount Sinai West (MSW)

A)



B)

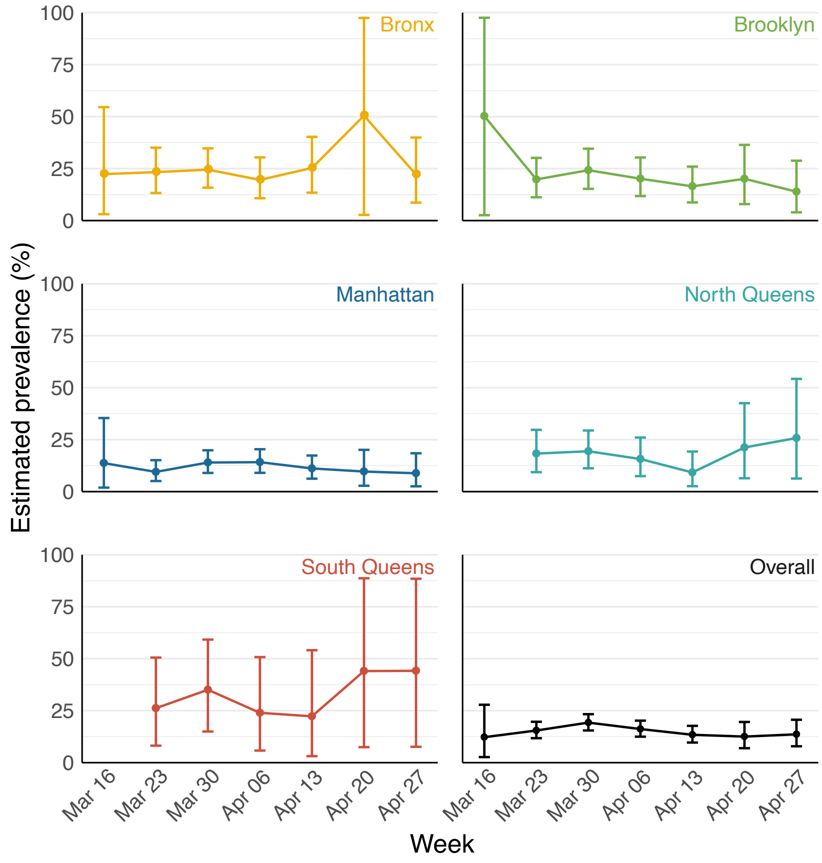


Figure 1. Posterior prevalence of SARS-CoV-2 infection by New York City borough. A) Posterior distribution of SARS-CoV-2 prevalence by borough (colors) and overall (black) across the study period. B) Weekly posterior prevalence of SARS-CoV-2 infection by borough with 95% credible intervals. For both panels, the test was assumed to have perfect specificity and 90% sensitivity. There were no recorded SARS-CoV-2 tests from patients with Queens ZIP codes during the week of March 16th.

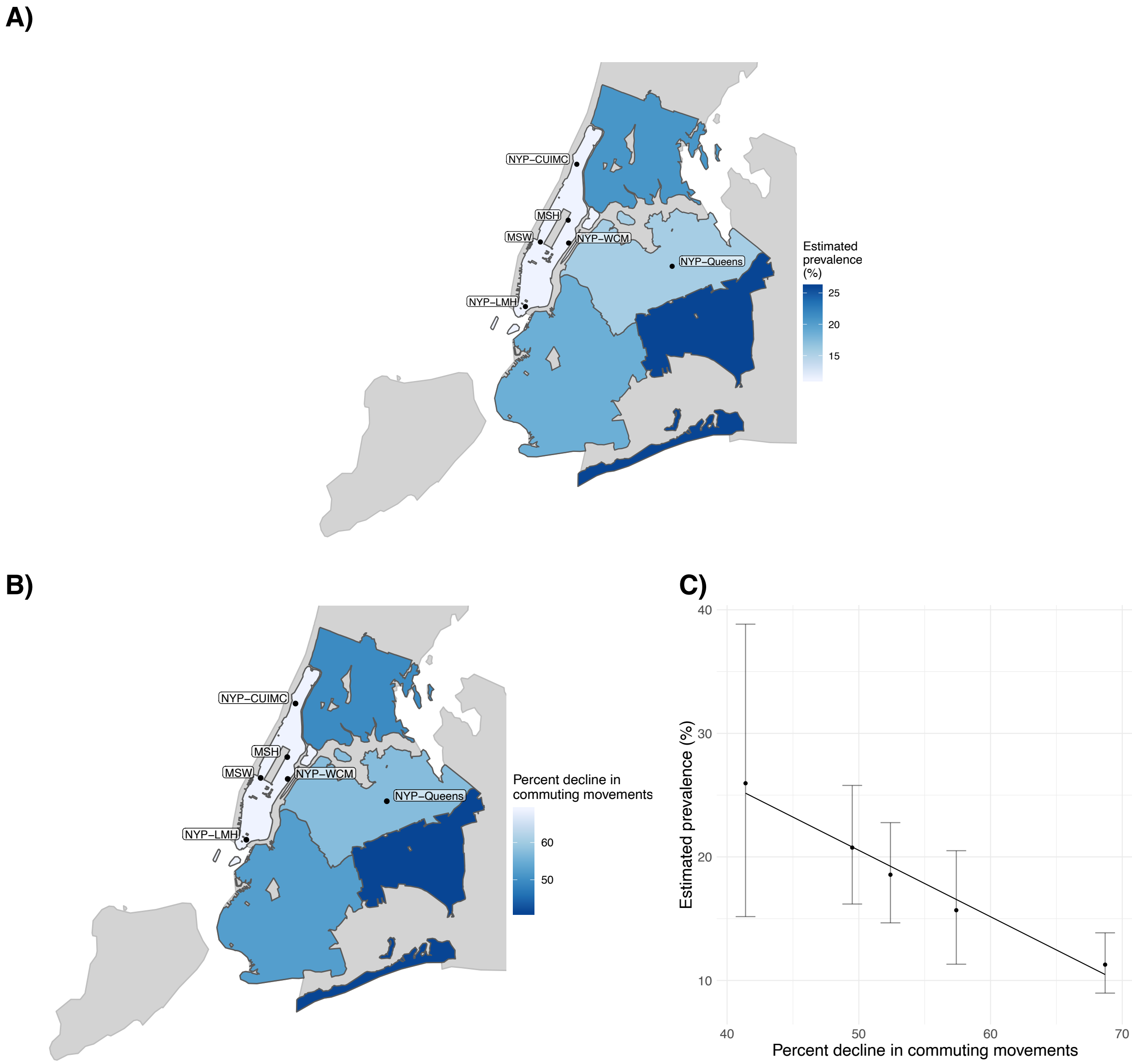


Figure 2. SARS-CoV-2 prevalence is lower in boroughs with greater declines in commuting movements. A) Estimated mean prevalence of SARS-CoV-2 infection by borough assuming a test with perfect specificity and 90% sensitivity. **B)** Percent decline in commuting movements by borough during the study period compared to the 45 days preceding Feb 26th, 2020. Commuting is measured as the total number of morning transits out of each borough and evening transits into each borough. Note the reverse scale, so that deep blue corresponds to higher prevalence in (A) and to a smaller decline in commuting in (B). **C)** Relationship between estimated prevalence of SARS-CoV-2 infection and decline in commuting movements by borough (R = –0.88, 95% CI –0.52, –0.99).

Supplement.

Borough	ZIP3
Bronx	104
Brooklyn	112
Manhattan	100, 101, 102
South Queens	110, 114, 116
North Queens	111, 113
Staten Island	103

Supplemental Table 1. 3-digit ZIP codes corresponding to the New York City boroughs.

Borough	Week	Number of tests	Number positive	Percent positive
Bronx	16 Mar	8	1	12.5
	23 Mar	60	12	20
	30 Mar	89	19	21.3
	6 Apr	66	11	16.7
	13 Apr	42	9	21.4
	20 Apr	16	0	0
	27 Apr	28	5	17.9
Brooklyn	16 Mar	3	0	0
	23 Mar	77	13	16.9
	30 Mar	85	18	21.2
	6 Apr	81	14	17.3
	13 Apr	79	11	13.9
	20 Apr	31	5	16.1
	27 Apr	30	3	10
Manhattan	16 Mar	14	1	7.1
	23 Mar	139	11	7.9
	30 Mar	173	21	12.1
	6 Apr	162	20	12.3
	13 Apr	138	13	9.4
	20 Apr	44	3	6.8
	27 Apr	48	3	6.2
North Queens	16 Mar	-	-	-
	23 Mar	59	9	15.3
	30 Mar	78	13	16.7
	6 Apr	62	8	12.9
	13 Apr	46	3	6.5
	20 Apr	19	3	15.8
	27 Apr	11	2	18.2
South Queens	16 Mar	-	-	-
	23 Mar	15	3	20
	30 Mar	17	5	29.4
	6 Apr	12	2	16.7
	13 Apr	8	1	12.5
	20 Apr	3	1	33.3
	27 Apr	3	1	33.3
Overall	16 Mar	25	2	8
	23 Mar	350	48	13.7
	30 Mar	442	76	17.2
	6 Apr	383	55	14.4
	13 Apr	313	37	11.8
	20 Apr	113	12	10.6
	27 Apr	120	14	11.7

Supplemental Table 2. Weekly number of SARS-CoV-2 tests (overall and positive) by borough.

Borough	70% sensitivity	80% sensitivity	90% sensitivity
Bronx	26.6 (20.8, 33.0)	23.4 (18.1, 29.1)	20.8 (16.2, 25.7)
Brooklyn	23.9 (18.8, 29.5)	20.9 (16.4, 25.7)	18.6 (14.7, 23.0)
Manhattan	14.5 (11.5, 17.8)	12.7 (10.1, 15.6)	11.3 (8.9, 13.9)
North Queens	20.1 (14.7, 26.3)	17.6 (12.8, 22.9)	15.7 (11.4, 20.5)
South Queens	33.4 (19.5, 49.7)	29.2 (17.0, 43.7)	26.0 (15.3, 38.9)
Overall	20.0 (17.8, 22.4)	17.5 (15.5, 19.6)	15.6 (13.9, 17.4)

Supplemental Table 3. Mean posterior percent population prevalence with 95% credible interval of SARS-CoV-2 infection by borough. The test is assumed to have perfect specificity and either 70%, 80%, or 90% sensitivity.

Borough	Percent decline
Bronx	49.5
Brooklyn	52.4
Manhattan	68.7
North Queens	57.4
South Queens	41.4

Supplemental Table 4. Changes in mobility by borough. The ‘percent decline’ column captures the reduction in transitions out of and into of each borough in the morning/evening during the study period compared to the 45-day period preceding February 26th, 2020. Aggregated morning trips out of the boroughs and evening trips into the boroughs here act a proxy for commuting to/from work.