



#virus

## Data Science Perspectives

# Has Social Distancing Worked? Geolocation Data Has Answers

- Using geolocation data, we seek to quantify the extent to which social distancing has helped reduce the transmission of COVID-19.
- We construct a customized “betweenness” measure from graph theory to measure how much a location is responsible for connecting people through proximity and visualize the results on heat maps to show social distancing in New York City.
- A critical quantity in epidemiology is the basic reproduction number,  $R_0$ , which describes the average number of people an infected individual will directly infect. If this number is  $>1$ , cases grow exponentially in early days; if  $<1$ , cases will decrease.
- We attempt to measure the reduction in number of contacts individuals have and estimate a 42% reduction after mid-March, which has a direct effect on the effective  $R_0$ , influencing whether the epidemic will grow exponentially.
- Reported numbers of  $R_0$  for COVID-19 have been 2.5-3.0. Our data suggest that social distancing may have reduced  $R_0$  to 1.25-1.98 since mid-March (less than the reduction suggested by other measures such as declines in subway ridership). That would make  $R_0$  closer to the flu, but not yet low enough to stop the outbreak. If it is representative, it suggests that current social distancing measures must remain in place or be strengthened.

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## Social Distance: Before and after the COVID-19 Outbreaks

We took over 10 million geolocation pings for about 1.3 million individuals from Complementics for January 1-14 and March 6-20 to create a before and after picture of what New York City looks like with social distancing in effect. We divided the city into over 2 million pixels and used this data to measure the effect of social distancing on New York City.

### How Places Connect People: Measuring Betweenness

We use a measure from graph theory called “betweenness” to measure how much locations in the city are responsible for connecting people through proximity. Briefly, two people can be connected for the purpose of disease transmission if they are in the same place, where a place in our study is represented by a roughly 50 square foot “pixel” in our map. Everyone who visits the pixel might infect one another, but if nobody leaves that location, they have limited capacity for inflaming an epidemic.

Thus, part of our intuition for social distancing goes beyond just that we should avoid crowded places. If one place is not crowded, but is visited by people who visit crowded places, then it might be overly responsible for disease transmission because these people can infect one another, so spread disease between crowded pixels.

If we look at how pixels connect people between pixels, we get a measure of how much transmission might be happening from that place in excess of its population density. If location A and B are both crowded, but people in place A never visit B, and vice versa, then there is no transmission path from A to B. Instead, if some A and B people both visit location C, C has high betweenness. Even though it might not be crowded, it connects crowded places.

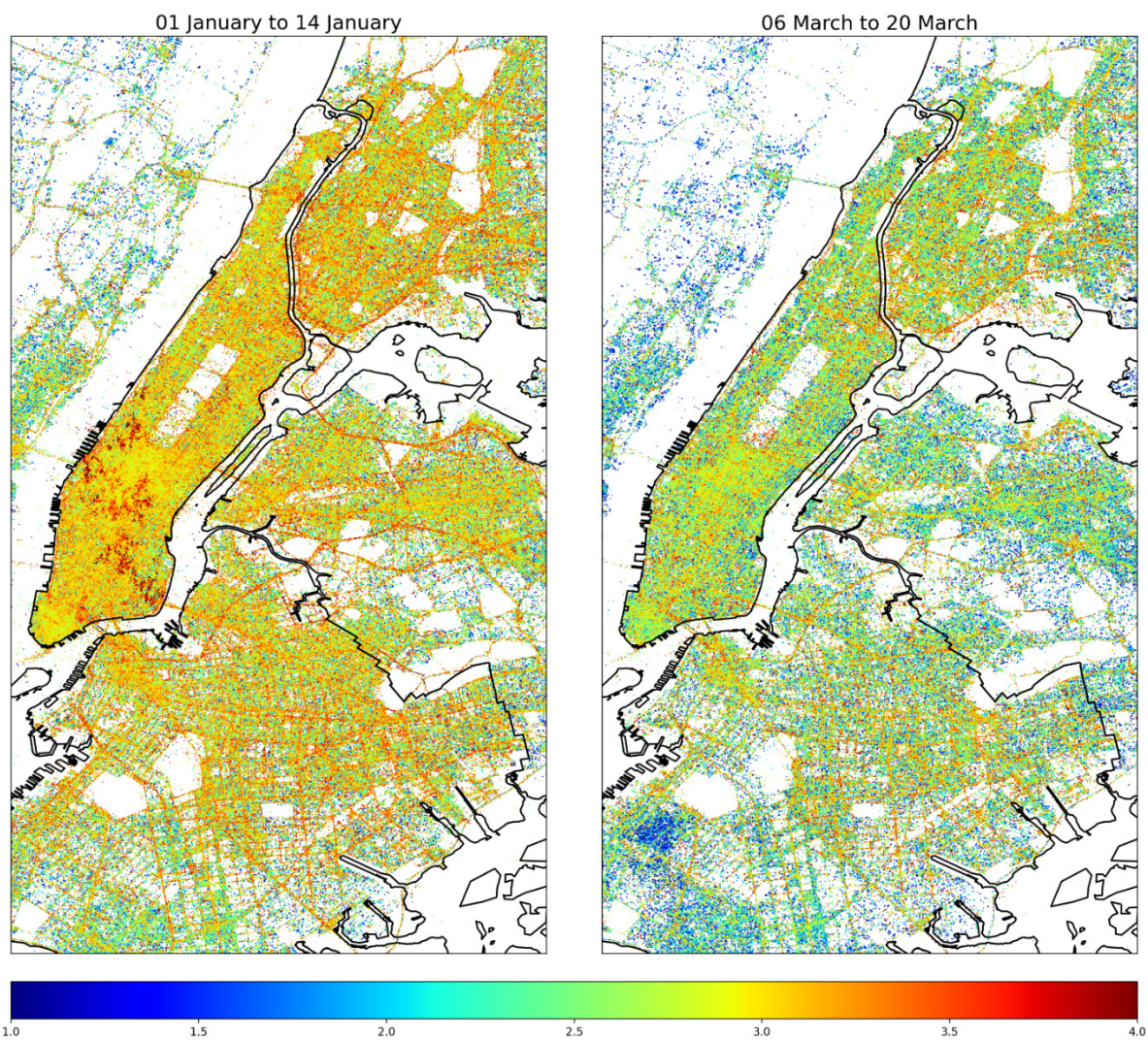
Our betweenness measure starts at 1, where all connections a pixel creates are only between visitors to that place. It increases as it connects people in other places, where some of its visitors travel elsewhere and might be responsible for transmission. That means it is a minimum when a location is on lockdown (blue areas in Figure 1), but increases the more freely and broadly its visitors travel.

There are some caveats here. We know transmission is unlikely when people are more than a few feet apart, but our threshold for visiting a place is about 50 feet. We also do not take into account whether people are actually exposed to one another, given that they are near each other. On roadways, for example, you might only be a few feet away from someone in the next car, but are not exposed to them.

Figure 1 shows a heat map of the betweenness of each location beyond what one would expect from its population density. A number of characteristics lead us to believe we are measuring the types of connections that are related to disease spread.

- In the early January period, there are hot spots that align well with popular areas for tourism and night life: Lincoln Center, the East Village, and the Lower East Side in Manhattan stand out in particular, suggesting that Manhattan hot spots likely attract people from all boroughs. There are also concentrations in the most significant office districts in midtown and in the large transportation hubs. To a lesser extent, there are also “warm spots” in other boroughs, particularly along major transportation corridors.
- These hot spots are all gone in the recent picture. People have stopped attending social events in Manhattan, which has reduced the betweenness of popular areas in the city.

FIGURE 1  
Excess Betweenness



Source: Barclays/Complementics

### Why Density Is Not a Sufficient Measure of Betweenness

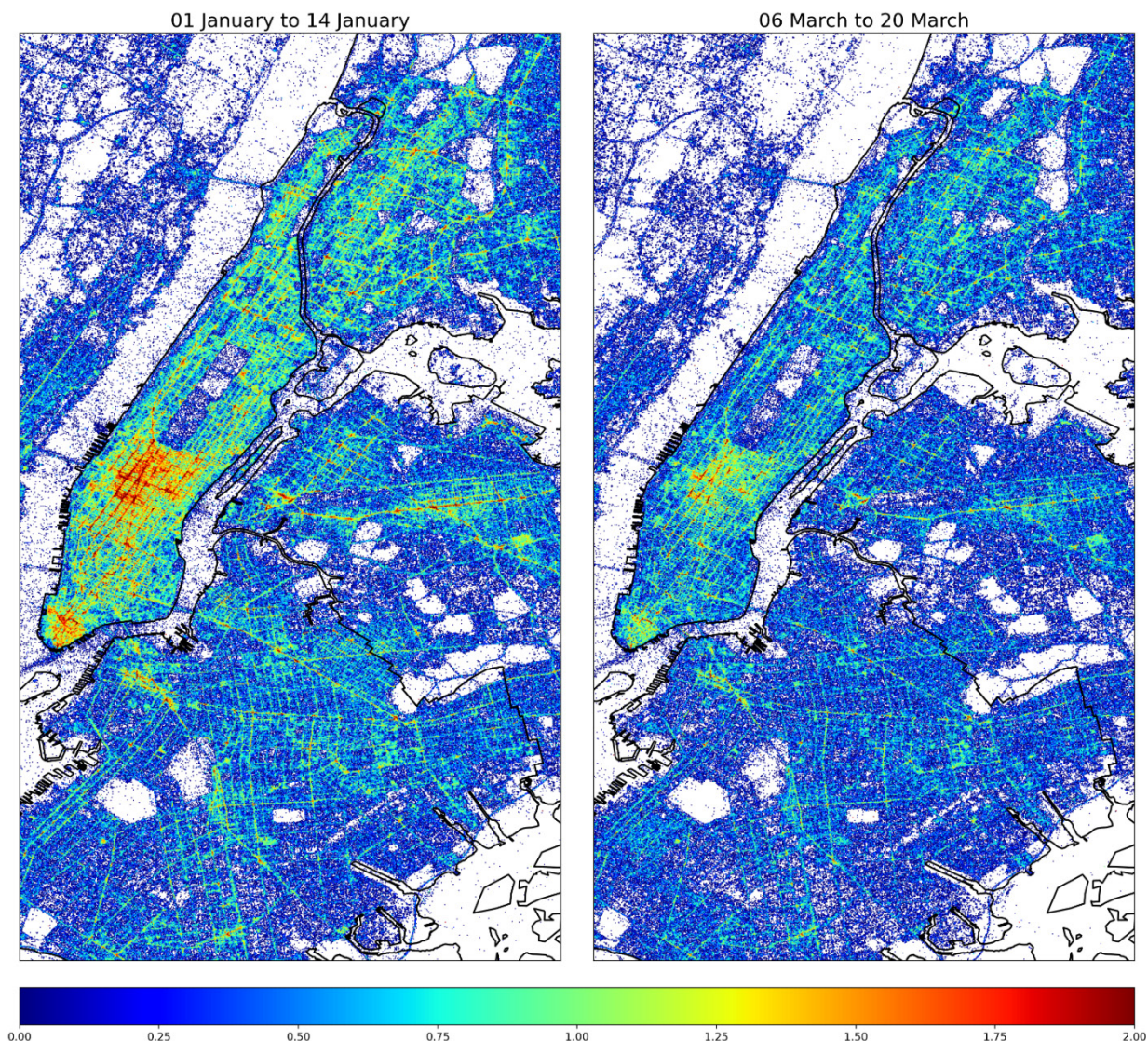
The simple story of population density tells much of the story of what social distancing looks like, but not the whole story. If everyone stays home, then one would see a density shift away from commercial areas. Residences would only connect the people who live there, and the epidemic would stop. Again, this is the case when our betweenness measure is a minimum, since houses only connect their residents. In that case, even in dense residential areas, because there is no transmission between places, there is no broad spread. By looking at transmission between locations, and measuring which pixels are responsible for this transmission, we get a more complete picture.

Even so, population density tells an important story. When commercial areas are crowded, they are generally connected to other places, so are likely locations for spread. Figure 2 plots the magnitude of people at different locations, where “2” means  $10^2$  people in a pixel. Manhattan is dense in its business districts, so we would expect a lot of transmission in these areas. We can see a great reduction in population density over time, so might hope contagion is reduced as well. We can examine the contact rate between individuals to get a more precise picture, as we discuss in the next section.



FIGURE 2

## Density Heatmap of New York City



Source: Barclays/Complementics

### Social Distancing Has Worked, but How Well?

Our density and betweenness measures tell us about the adoption of social distancing more than the effect of social distancing on the epidemic. They resonate with the idea that we should not visit crowded places and should stay away from people who do, but they stop short of connecting directly to epidemiological parameters that drive case volume over time.

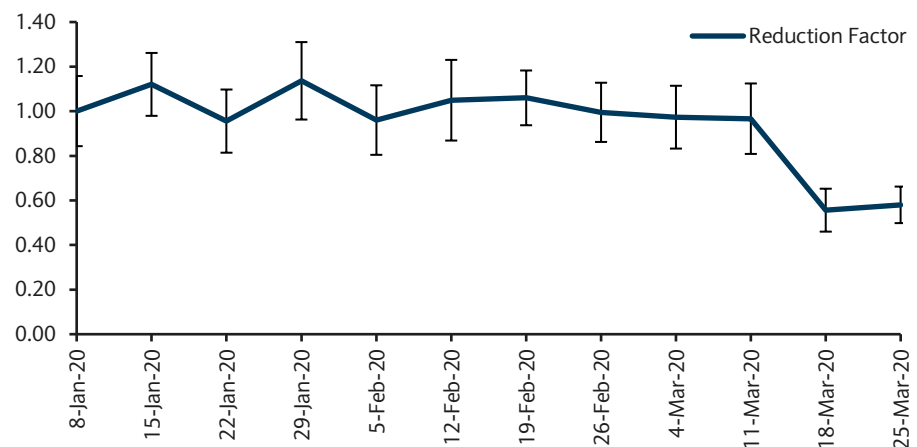
A critical quantity in epidemiology is the basic reproduction number,  $R_0$ , which describes the average number of people an infected individual will directly infect. If this number is greater than 1, an epidemic will grow exponentially in its early days. Less than one, and it will decay exponentially.

An important nuance is that the fewer social contacts a person has, the fewer people he or she can transmit to, so effectively the lower the  $R_0$ . Technically, it is the epidemic threshold - the critical value  $R_0$  must exceed to drive exponential growth - and not  $R_0$  itself that

changes. The result is the same: if we can halve the number of contacts, we will double the transmission rate required to reach exponential case growth. This is the point of social distancing: reducing or ending the spread of the epidemic by raising the critical threshold. We have seen from the preceding sections that social distancing is in effect. Has it had the desired effect of raising the epidemic threshold?

The epidemic threshold is directly calculable from the number of contacts people have. We can try to measure this directly from our geolocation data. If we say each person is connected to those within the same 50 square foot pixel, and assume our sampling rate of individuals is constant, then we can measure the reduction in contacts each individual has from our geolocation data, as in Figure 3.

FIGURE 3  
Ro Reduction Factor



Source: Complementrics, Barclays Research

Comparing the number of contacts each individual has in the most recent week of March 25, 2020, with the number on January 8, 2020, we see a 42% reduction in the number of contacts. By this metric,  $R_0$  would be reduced by a factor of  $0.58 \pm 0.08$ . The broadly reported numbers for  $R_0$  have been 2.5-3.0, so these data support a reduction in  $R_0$  to 1.25- 1.98.

Of course, there are some major caveats:

- Our subway ridership signal (*Data Science High Frequency Indicators Update: Running Out of Room for Worse*, March 24, 2020) shows that there may have been a much greater reduction in contacts. It is possible that our geolocation contact number understates the reduction in contacts, as these two number disagree. It is also possible that because subway entrances are overly dense, the reduction in ridership might be a bad proxy for the reduction in contacts.
- We have ignored cluster effects and focused on how individual connectedness affects the epidemic threshold. It might be important to treat each borough separately, for example.
- We have allowed connectedness within a large area (~50 ft sq pixels), including connections from cars on the street. If those contribute an outsized proportion of contacts, we might overstate the number of contacts people have. If subway ridership has shifted to car ridership, we might not see a drop in actual connectedness where there was one.

If one believes the reduction number we are seeing, then one would have to conclude that the epidemic has been reduced to a level potentially so low that it is comparably as

contagious as the flu. If one believes we have understated the reduction (eg, one prefers the subway signal numbers), then one would believe we may have already reached a level where the epidemic is in check and case numbers should start to decline in the near future.

We believe there is enough room for positive bias in the contact counts, especially due to overcounting contacts from car traffic, that our reduction factor measurement might be biased toward 1 (meaning no reduction). That would mean social distancing measures have been even more effective than what is evidenced in this data, possibly enough to drop the effective  $R_0$  below the epidemic threshold.

In either case, it appears critical that social distancing measures stay in place or are strengthened. It is clear that they are having an effect.



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