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Global cities, hypermobility, and Covid-19

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ABSTRACT

The relationship between cities, globalization and mobility has produced recurring urban challenges over time. This article examines how mobility networks can turn global cities into Pandemic Gateways. Our hypothesis is that global cities became the gateway by which COVID-19 was introduced to many countries through the hypermobility of infected international travelers. To assess this transmission mechanism, we assembled data about the population and COVID-19 cases in global cities and their associated countries, comparing their infection rates on a fixed date.

We demonstrate that most global cities followed a common pattern in the pace and intensity of COVID-19's spread during the first wave of the pandemic. Among our global cities sample, 75% served as the gateway through which COVID-19 was diffused within their respective countries. This trend reached 90% in a subset based upon the urban hierarchy among global cities. Hypermobility, which we demonstrate contributed to the mechanism by which global cities diffused COVID-19 initially, is also correlated with the global cities hierarchy, as supported by air travel data. Our findings suggest the need to appreciate why global cities can serve as gateways of pandemic diffusion, while also seeking to understand why some did not function in this way.

1. Global cities: pandemic gateways of the 21st century

This article considers the ways in which globalization and mobility have once again intersected to turn a majority of global cities into pandemic gateways. In many ways, the evidence that we analyze echoes an old story about the spread of disease that goes back to the ancient world’s trading networks and nodes. Among the many characteristics of global cities, the one most relevant to understanding a pandemic’s diffusion, whether in Byzantium or Brooklyn, is the concentrated flow of people coming together into a hub of exchange.

We thus examine the function of global cities during a pandemic through a mobility lens, extending the approach that John Urry (2000) introduced in Sociology Beyond Societies: Mobilities for the Twenty-first Century, where he considered how the ever-increasing flow of people and objects in a borderless world generates new dynamics in both transportation and society. Specifically, we analyze the amplifying effects on diffusion of communicable disease created by global aviation networks and cross border mobility.

Saskia Sassen (2002) demonstrated that global cities both depend on, and are defined by, flows of capital, information, and people. The sum of these mobilities leads in a consistent direction – more travel by people who can carry infectious diseases farther and faster than ever before. Brown and Moon (2012) analyze how globalization increases health challenges through fostering cross-border mobility, but the role of the global city in transmitting the novel coronavirus in early 2020 became increasingly apparent and thus calls for applying an urban network focus to mobility analysis during the first wave of a global pandemic. Comprehending the disruptions that were unleashed in 2020 calls for better understanding the role that global cities played in the dissemination of the first wave of the Coronavirus pandemic, which is the analytical focus of this article.

To understand the mobility dynamic that is generated by the global city, it is helpful to recall Peter Hall’s (1997) insight that global cities are clusters of human activity attracting business and leisure tourism with implications for multiple sectors such as transportation, communication, entertainment and services. Some of these interactions take place in public spaces within cities, such as stations, ports, airports, and other hubs of people and movement, identified by Manuel Castells (2018), as social exchangers, or communication nodes. The resulting network of social exchange, when added to the context of the growing networked cross-border transactions among global cities elucidated by Saskia Sassen (2018), generates an ever-expanding demand for mobility between

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In the 2003 SARS outbreak in Toronto, Canada, Ali and Keil (2006) discuss how the modern emergence of a global urban network and international migration has contributed to spreading epidemics of infectious disease. Their analysis demonstrates how global networks can pose increasing risks of disease transmission and outbreak response as their velocity of movement increases. Based on analogous concepts, Fuller (2016: 345) assessed the biopolitical effects in the Hong-Kong post-H1N1 pandemic in 2003. In his study, he used the term “Pandemic City” to illustrate the relations between human flows, urban agglomerations and health issues, noting that global cities “are considered both as the breeding grounds and as the dissemination engine of infectious diseases.” Both of these authors’ findings have been validated by the first wave of the novel coronavirus pandemic in 2020.

According to the timeline created by the World Health Organization (WHO, 2020a), “the first human cases of COVID-19, the disease caused by the novel coronavirus, were reported in Wuhan City, China, on 31 December 2019.” Less than four months later, on 11 March 2020, WHO officially characterized COVID-19 as a pandemic (WHO, 2020a). Since its first identification, the COVID-19 outbreak has challenged the world with a combination of speed, scale of transmission, and severity (WHO, 2020b). The mobility disruption that began with an astonished 9 million people put under quarantine and confined inside their homes in Wuhan in China in January 2020 (Yuan et al., 2020), grew into something previously unimaginable in the modern era. Four months later, according to the fourth report from the United Nations World Tourism Organization (UNWTO, 2020), 100% of destinations worldwide had imposed COVID-19 related travel restrictions, and 45% have borders entirely or partially closed for international tourism.

Considering the magnitude of the ongoing COVID-19 pandemic, it is likely that no article length analysis would be capable of fully explaining the causes and consequences of the novel coronavirus. Thus, our work does not try to offer a comprehensive pandemic explanation. This article will not assess topics such as the adaptation or reconfiguration of global cities caused by the pandemic, influence of population density on infection rates, and mobility patterns of community transmissions, among others, because it would require different data and analysis, and which should therefore be addressed in other research findings. Instead, we focus on understanding the initial propagation of the novel coronavirus across the globe. This knowledge regarding the onset of COVID-19 outbreaks in global cities and their relationship to the pandemic’s progression in associated countries offers a necessary contribution to building more complete awareness of how the world has been changed since 2020. Our null hypothesis is that the majority of global cities have been the gateway by which COVID-19 was introduced to their respective countries through the hypermobility of infected international travelers.

We begin by considering the relationship between globalization and hypermobility based on airline data and the stringency index (Hale et al., 2021) in order to contextualize mobility data and to provide a static analysis of how the virus initially affected our sample of global cities differently than other human settlements. Subsequently, to assess the COVID-19 transmission mechanism, we assembled data about the population and COVID-19 cases in global cities and their countries, comparing the rates of cases between cities and countries on a fixed date. This comparison reveals whether there is a relation or not between COVID-19 infection rates in a global city and infection rates within the country as a whole.

The goal of this comparison is to determine whether a majority of global cities were functioning as COVID-19 pandemic gateways during the first wave of the pandemic. In exploring our hypothesis, we make no claims that global cities are responsible for COVID-19, nor that COVID-19 is mainly a global cities problem, or even that if it were not for global cities, smaller cities and rural places would have remained untouched by the virus. However, we seek to demonstrate that the initial spread of the virus was extended in space and accelerated across time, associated with the flows of people between global cities. In other words, although it is not possible for us to say how the novel coronavirus pandemic would
have unfolded without the network of global cities connected by hypermobility, it is possible for us to discern a particular configuration for this pandemic’s initiation due to the gateway function performed by a majority of global cities.

And while building this understanding of pandemic gateway function will not be sufficient to resolve the current global public health crisis, it could prove valuable to better controlling future pandemics by highlighting measures that can better manage the intersection of international mobility flows with infectious diseases.

Many authors have begun to assess the relationship between transportation modes and COVID-19 (Sun et al., 2020; Zheng, 2020; Ito et al., 2020; Peeri et al., 2020) as well as globalization and transportation (Cheung et al., 2020; Gossling et al., 2009; Rodrigue, 2006; Smith & Timberlake, 2002; Urry, 2003). However, to the best of our knowledge, this study is the first to examine empirical evidence of COVID-19 infection rates from the comparative results of an official Global and World Cities (GaWC) ranking (Taylor et al., 2002), where the spread of the virus is analysed based on the city’s function within a global network instead of examining its transportation infrastructure and travel flows more generally.

2. Pandemic trajectories in the era of hypermobility

The amplified relationship of time, space, and speed of mobility and its effect on public health has been directly associated with international travel since the early days of commercial aviation as noted by Budd et al. (2009). Such a relationship was assessed by Ali and Keil (2006) who demonstrated that pandemics now have the potential to spread rapidly and widely due to modern transportation technology, particularly jet aircraft. Civil aviation as a mode of global mass transportation multiplies public health risks because as the journey takes less time compared to earlier mobility by ship, infected travelers can now remain asymptomatic during travel and even upon their arrival (Karlen, 1996). The relatively long incubation time of the novel coronavirus and the inconsistent appearance of symptoms among those who are infected turn out to be well suited to widespread diffusion through global aviation networks. This challenge is also identified by Nakamura and Managi (2020), who recommend an immediate and drastic reduction in air travel to support global health preventive measures in their analysis of importation and exportation risks of COVID-19 via air travel.

Long before the 2020 pandemic arrived, the powerful effect of civil aviation in fostering socioeconomic relationships across global networks meant that flying had become an indicator of significance among global cities (Hall, 2009; Smith & Timberlake, 2002). Gossling et al. (2009) discuss hypermobile trends and conclude that globalization and transportation drive increasing demand for air travel. Future research will need to determine whether this pandemic could permanently disrupt the long run trend of aviation growing along with the importance of global city nodes in worldwide networks.

Marine transportation also poses public health risks that may be as high as those found on aircraft (Ito et al., 2020) or even higher, as reported by a research team from the U.S. Centers for Disease and Control Prevention (Moriarty et al., 2020). The Miami Herald COVID-Cruises Project (Blaskey et al., 2020), in concurrence with the CDC’s risk assessment, pointed out that up through 1 August 2020, 28% percent of the cruise ship fleet worldwide had registered COVID-19 outbreaks, yielding a total of 3651 cases and 102 deaths aboard 72 different ships. Cruise ship travel was largely curtailed during 2020 in order to limit Covid transmission.

Xu et al. (2019) reviewed the diffusion patterns of the H1N1 flu in Mainland China by analyzing a highway network linking 333 cities, concluding that both the road traffic network and socioeconomic variables, such as population density, income, and number of hospitals and colleges among others had significant effects on virus distribution. They recommended these variables as relevant information sources for preventive measures in future pandemics. The global supply chain may also be serving to further concentrate flows in global cities, as shown by Negrey et al. (2011). Such freight flows between cities and towns were directly related to H1N1 transmissions in China, according to an assessment by Xiao et al. (2011).

The novel coronavirus did not concentrate on a specific mobility mode. Air, sea and land transportation each supporting hypermobility

![Fig. 1. International tourist arrivals, 2000–2019 and 2020 scenarios (millions). Source: Adapted from the World Tourism Organization figures (UNWTO, 2020; UNWTO, 2021).](image-url)
contributed to the global and local diffusion of COVID-19, but in different ways. Carten et al. (2020) found a direct relationship between the total number of COVID-19 cases reported in Italy on a particular day and the mobility rates of the Italian population 21 days before. Hadji-demetriou et al. (2020) also found that in the U.K. mobility levels are connected to the number of deaths caused by COVID-19.

Peeri et al. (2020) argue that increased globalization and the extensive connection options to local and international nodes from the epicenter of COVID-19 in Wuhan were among the reasons for a faster and broader diffusion of the virus when compared to earlier SARS and MERS outbreaks. Local transmission and mobility were also assessed by Zhang et al. (2020) with important findings demonstrating that the frequency of air flights and high-speed trains connecting Wuhan to other Chinese cities influenced the resulting number of COVID-19 cases in the destination city.

Annual international tourist arrivals reported by the World Tourism Organization (UNWTO) between 2009 and 2020 are presented in Fig. 1. In 20 years, from 2000 to 2019, the number of arrivals has grown by 117%. This represents a yearly average growth of 5.8%, or almost 40 million new arrivals per year. Only two years saw any decrease. First, in 2003, during the SARS (Severe Acute Respiratory Syndrome) outbreak, and then during the global financial crisis of 2009. During this period, the world population has grown 26%, at an annual rate of 1.3% (United Nations, 2019). International tourism growth thus reflects an important dimension of global hypermobility.

COVID-19 suddenly disrupted travel patterns and socio-spatial relationships. The evidence clearly suggests that the pandemic derailed tourism’s global growth in 2020. The UNWTO estimates a drop of up to 73% in international tourist arrivals for 2020, as shown in Fig. 1. However, the hypermobility impetus of international travelers and the global economic forces stimulating air transportation may have played a particular role in the global diffusion of the COVID-19 pandemic, as demonstrated by Sun et al. (2021). The authors assessed the synchronization between air transport connectivity and the number of COVID-19 cases worldwide, showing that most countries reduced international flights only after April 10, one day after the first 100 days of the pandemic. The authors concluded that almost all countries responded too late to contain the COVID-19 pandemic.

The pandemic’s long-term impact on global cities remains unknown. Still, many scholars who considered the first wave of infections and their consequences have drawn bleak conclusions for the future of globalization, suggesting that travel barriers, exercises of sovereignty, tourism limits and immigration controls will be increasingly restrictive due to a sustained nationalism generated by the carnage from coronavirus (Chan, 2020; Hood, 2020; Pross, 2020; Steil, 2020). More restrictive borders are seen to foster an eventual return of local production and a shortening of the global supply chain for traded goods (Brands & Gavin, 2020; D’Urbino, 2020).

The global pandemic’s trajectory in the Fall of 2021 poses many questions. Our response to this uncertainty is to construct an analysis that can shed some light on a particular relationship between hypermobility, urban gateways, and viral transmission that contributed to this pandemic becoming a global, and possibly world-changing, phenomenon. Since humans are a primary vector of transmission for the novel coronavirus, and travel volumes are now much greater than they were in past decades, let alone centuries ago, there is a need to understand the impact of hypermobile travelers spreading disease through the networks that connect global cities. This search for understanding anchors our central research question: did a majority of global cities function as gateways of COVID-19 transmission into their respective countries at the onset of the 2020 novel coronavirus pandemic?

### 3. Methodology and data

The methodology used to assess our research question is relatively straightforward. First, we created a list of global cities to structure the dataset for our research. Then, we defined the variables that would be aggregated within the dataset and established the time frame for our analysis. Data enrichment, with its attendant challenges and requirements, comprised the third step. Finally, we advanced a comparative analysis between the variables to understand their relationships across time and space.

The variables used to assemble our dataset were divided into three subsets: air transportation; stringency index, and; COVID-19 and population. While the first two categories are used to assess the relationship between global cities and hypermobility, the third data domain is needed to more fully answer our research question. The primary equation to test our hypothesis that most global cities functioned as pandemic gateways in early 2020 consists of comparing the rate of infection from the first wave of COVID-19 within a global city to the overall rate of infection in its respective country, within the same timeframe at the global pandemic’s onset. We normalize the extent of infection in the pandemic by considering COVID-19 cases divided by the population of a city or country. This enables us to create a key indicator designed to capture the percent change between pandemic infection rates, named Net Pandemic Ratio (NPR) as expressed through the formula below:

\[
NPR = \frac{\text{City COVID Ratio per capita}}{\text{Country COVID Ratio per capita}} - 1
\]

where the City COVID Ratio per capita, represents the number of COVID-19 cases in the city on 9 April 2020 divided by its population, and the Country COVID Ratio per capita the number of COVID-19 cases in the country on the same date divided by its population. If the resulting indicator Net Pandemic Ratio (NPR) turns out to be greater than zero, then our hypothesis of a global city being a pandemic gateway is supported for that city.

#### 3.1. Categorizing global cities

Scholars have proposed different definitions for global cities (Ahramson, 2004) that could lead to many possible lists of global city candidates. Recognizing this heterogeneity and acknowledging critiques about Western-dominated approaches to the way in which global cities lists are constructed (Robinson, 2002), we selected a dataset from the Globalization and World Cities Index (GaWC), created by Taylor et al. (2002: 100), described as “THE GAWC INVENTORY OF WORLD CITIES. (sic)” This analytical framework has been used in multiple academic publications with more than 150 citations (Google Scholar, 2020). The GaWC dataset identifies 55 cities, from 33 countries, divided into three tiers, Alpha, Beta, and Gamma, organized according to their global relations measured on a 12-point scale. Their sampling strategy consisted of evaluating a universe of 122 cities, classifying each of them based on

| A. Alpha world cities |
|-----------------------|
| 12 points: London, Paris, New York, Tokyo |
| 10 points: Chicago, Frankfurt, Hong Kong, Los Angeles, Milan, Singapore |

| B. Beta world cities |
|-----------------------|
| 9 points: San Francisco, Sydney, Toronto, Zurich |
| 8 points: Brussels, Madrid, Mexico City, Sao Paulo |
| 7 points: Moscow, Seoul |

| C. Gamma world cities |
|-----------------------|
| 6 points: Amsterdam, Boston, Caracas, Dallas, Dusseldorf, Geneva, Houston, Jakarta, Johannesburg, Melbourne, Osaka, Prague, Santiago, Taipei, Washington |
| 5 points: Bangkok, Beijing, Rome, Stockholm, Warsaw |
| 4 points: Atlanta, Barcelona, Berlin, Buenos Aires, Budapest, Copenhagen, Hamburg, Istanbul, Kuala Lumpur, Manilla, Miami, Minneapolis, Montreal, Munich, Shanghai |

Adapted from Taylor et al. (2002: 100).

| Table 1 The GaWC inventory of world cities. |
|-----------------------------|
| A. Alpha world cities |
| B. Beta world cities |
| C. Gamma world cities |

| A. Alpha world cities |
|-----------------------|
| 12 points: London, Paris, New York, Tokyo |
| 10 points: Chicago, Frankfurt, Hong Kong, Los Angeles, Milan, Singapore |

| B. Beta world cities |
|-----------------------|
| 9 points: San Francisco, Sydney, Toronto, Zurich |
| 8 points: Brussels, Madrid, Mexico City, Sao Paulo |
| 7 points: Moscow, Seoul |

| C. Gamma world cities |
|-----------------------|
| 6 points: Amsterdam, Boston, Caracas, Dallas, Dusseldorf, Geneva, Houston, Jakarta, Johannesburg, Melbourne, Osaka, Prague, Santiago, Taipei, Washington |
| 5 points: Bangkok, Beijing, Rome, Stockholm, Warsaw |
| 4 points: Atlanta, Barcelona, Berlin, Buenos Aires, Budapest, Copenhagen, Hamburg, Istanbul, Kuala Lumpur, Manilla, Miami, Minneapolis, Montreal, Munich, Shanghai |
the presence of global specialized firms within four economic activity segments: accountancy, advertising, banking/finance and law. In each of these segments, a city could score zero (not qualified) up to three points (prime center), and the sums of these scores produced the world city ranking, ranging from 0 to 12. The group of world cities were then defined by the Alpha Cities, which are those scoring higher than 10, followed by Beta cities scoring between 7 and 9, and lastly, the Gamma group, including final scores of 4, 5 and 6. This population of global cities is depicted in Table 1:

Apart from the cities included in Table 1, Taylor et al. (2002) identified 67 more cities as having evidence of world city formation processes, but the evidence was not strong enough to classify them as major world cities. An updated version of this list would inevitably present changes, but even with such a limitation, this set of cities presented a justifiable starting point for our analysis.

3.2. Analytical timeframe

Our timeframe is important in the calculation of infection rates, as it aims to capture a moment where the global nature of the novel coronavirus pandemic was first coming into focus in order to understand whether the pandemic’s emergence had an urban dynamic, in addition to being a global phenomenon. The first one hundred days of the pandemic stood out as a recognized milestone for many countries because it offered the ability to identify important characteristics of their responses (Sun et al., 2021; United Nations, 2020; Zhou et al., 2021). According to the WHO (2020a) Timeline, 9 April 2020 stands precisely at the 100-day mark after Chinese authorities reported their first case and, for this reason, we adopted it as the temporal reference point for obtaining COVID data from cities and countries.

Our analytical goal for the infection rates was to compare city and country information on exactly the same day for every city and country specified in Table 1. Through the calculation of the Net Pandemic Ratio (NPR), by dividing city infection rates by country infection rates, we are able to determine whether or not the global city was impacted by the pandemic either ahead of, or following, the impact across its country. As our study is not designed to compare a time series analysis of infection rates between countries or cities, relying upon a fixed date across our entire dataset provides the knowledge needed to answer our research question, to understand the role of global cities in spreading the virus during the pandemic’s first wave. Variables measuring air transportation volumes and population figures were used in different time frames according to their availability, as described below.

3.3. Air transportation flows and the stringency index

Three information sources were used to measure the extent of hypermobility within our list of global cities. First, we obtained information on total air passenger volumes per country in 2019, including both domestic and international flights (The World Bank, 2021). The second source aims to capture the extent of international mobility from China to our list of countries where global cities are found. It relies upon country-to-country information from 2016, estimating the paired “origin-destination” trips by using international tourism and air passenger traffic data, included in the “Global Transnational Mobility Dataset” available on the Knowledge Centre on Migration and Demography (KCMD) Data Portal from the European Commission (Ricchietti et al., 2019). The third, and most relevant source, aligns air travel directly with metrics for global cities based on the methodology created by Sun et al. (2017), in which every airport within 1.5 h driving distance was associated with each global city included in our list. After selecting the airports, two indicators were developed based on data from Flightradar24 for the year 2020, one dedicated to measure the share of international flights identified as the “International Ratio,” and the second one used to reveal the city’s centrality in global aviation networks, in other words, the number of countries that can be reached from each city using direct flights, labeled as “Global Direct Reach.”

We assessed government responses to the pandemic using data from the Oxford COVID-19 Government Response Tracker - OxCGRT (Hale et al., 2021). Among the available indicators, we selected the stringency index because it directly focused on mobility restrictions. The stringency index measures eight different indicators including: school closing; workplace closure; canceling public events; restrictions on gathering; stop public transport; stay at home requirements; restrictions on internal movement, and; restriction on international travel. We applied the national figures on stringency to represent the urban condition for all cities, outside the U.S. As stringency data was disaggregated, for those cities, we used their respective state data to represent each American city directly. We used data from 11 March 2020 to demonstrate mobility restriction measures in our sample because this was the day when WHO classified COVID-19 as a pandemic, and we also used data from 9 April 2020, aligning with the time frame used to assess the Net Pandemic Ratio (NPR) indicator.

3.4. COVID-19 and population

Once we had identified our sample of global cities, we defined our variables to assess COVID-19 case rates in relation to population. This yielded four variables: City Population (A), City COVID Cases (B), Country Population (C), and Country COVID Cases (D). By comparing the city directly with the country it is located in, we avoid the measurement problems of reconciling different testing strategies and restriction measures that have been raised by Middelburg and Rosendaal (2020).

Urban and national population figures were obtained from government statistical records. As changes over time are usually modest, when projections for 2020 were not available, the most recent census data was used. Population of the city and the country were always obtained from the same source and year for each pairing. This approach resulted in 24 different sources of population data, mostly from federal, provincial or city government agencies, as presented in Appendix 1. Singapore was excluded from the list due to its city-state status, which yielded the same values for both city and country populations.

The data source for COVID-19 cases in each country was the dataset “Coronavirus Pandemic (COVID-19) – the data” available on the Oxford University website “Our World in Data” (Ritchie et al., 2020). The only exception was Turkey, where the local source was kept because the information for the city of Istanbul, available only for 1 April 2020, also contained the country figures, which were considerably different than those reported in the Oxford University data.

Collecting COVID-19 case data within cities proved challenging. For disaggregated COVID-19 data at the urban scale, there are no global patterns, no standard dashboards, no unified reports, and therefore the sources vary from official agencies to educational institutions, non-government organizations (NGOs), and even to media portals. These problems have been highlighted by the World Health Organization in its COVID-19 strategy update report (WHO, 2020b: 13), which stresses the challenges involved in accessing disaggregated global data due to a lack of standardized data architecture and harmonized public health reporting mechanisms.

Many local sources for COVID-19 case data were obtained for our assessment, resulting in 46 different sources for this variable, mostly acquired from local governmental agencies or big data portals, shown in Appendix 2. Only the city of Taipei, in Taiwan, had to be excluded from our analysis because of unavailable COVID-19 data. Additionally, in aiming to produce a more comparable set of data, data on population and COVID-19 cases from the province of Hubei in China were excluded from that country’s figures. This province represents the epicenter of the outbreak and the study aims to understand the infection flows from there to global cities, as identified in our research question. Therefore, it made more sense to evaluate Chinese global cities without Hubei’s figures.
4. Descriptive statistics

This section was organized to highlight the position of global cities in the pandemic's first wave. It contextualizes hypermobility in our sample to then assess its relationship with the GaWC ranking. Next, we used data from the stringency index (Hale et al., 2021) to exemplify the mobility disruption caused by COVID-19. Finally, after connecting global cities and hypermobility, we tested our hypothesis by identifying whether or not the cities in the GaWC ranking were pandemic gateways to their respective countries and whether their classification as Alpha, Beta, or Gamma cities had any influence on the Net Pandemic Ratio (NPR), International Ratio, and Global Direct Reach indicators.

### 4.1. Global cities and hypermobility

Aviation, as explained by Rodrigue et al. (2020), is a vector of quick and extensive disease dispersion which has changed the diffusion of pandemics and, as noted by Karlen (1996), represents the greatest risk of transporting infectious diseases globally. We collected data on both national civil aviation and disaggregated passenger volumes by airport and city to produce the analysis of hypermobility in our sample. Such analysis is justified for aviation as questions about containment, disease control, and biosecurity are usually associated with airports (Warren et al., 2010).

The growth rate in air transportation volume in our sample is even higher than the global average for international tourism referenced.
earlier. Data on international and domestic air passengers carried per year (The World Bank, 2021), based on information from the International Civil Aviation Organization and Civil Aviation Statistics of the World Bank, shows that our sample accounted for 78%\(^1\) of the total passengers carried worldwide in 2019, growing 133% from 2000 to 2019. Another interesting piece of evidence about global mobility is found in the Global Transnational Mobility Dataset, which reveals that in 2016, 75.19%\(^2\) of all international passengers transported from China (reporting country) had one of the countries from our sample as their destination (Recchi et al., 2019).

The association between these figures with our global cities sample is explored using two indicators developed by Sun et al. (2017) namely the “International Ratio” and the “Global Direct Reach,” applied to data gathered from FlightRadar24 for 2020. Both indicators were calculated based on consolidated information for each city, considering airports within 1.5 h driving distance from the city center. Table 2 lists the airports included in each city as well as both indicators. The average value of the International Ratio equals 0.51, on a scale from 0 to 1, meaning that in average 51% of the total flights serving airports associated with our global cities sample, are international flights. The Global Direct Reach resulted in an average of 62 countries with direct connections from each global city, a figure that is 637% higher than the average of the total dataset including almost 3000 airports. The latter indicator when grouped according to the GaWC classification of Alpha, Beta, and Gamma cities shows that the first tier of global cities reaches an average of 88 countries with direct connections (Global Direct Reach), the second tier of cities connects to an average of 63 nations, and finally, 57 direct connections are the average among airports in the third tier. These results indicate a clear connection between globalization, represented by the GaWC ranking, and the degree of international hypermobility expressed by the Global Direct Reach indicator.

4.1.1. Disrupting hypermobility

The time lag in interrupting flights once the pandemic had been declared was documented by Sun et al. (2021) and applied to mobility restrictions, more generally as captured in the stringency index and illustrated in Fig. 2. This variable, identified as the stringency index, measures mobility on a scale from 0 to 100 points, where 0 represents no mobility restriction or containment measures and 100 represents a total lockdown. On 11 March 2020, when COVID-19 was declared to be a pandemic, our sample exhibited a stringency index average of 30.6 points, with only two Italian and two Chinese cities presenting mobility restrictions above 56 points with 85.19 and 81.02 points (country figures), respectively. However, less than one month later, on 9 April 2020, the average in our sample of global cities grew to 75.9, including only four cities, Stockholm, Tokyo, Osaka, and Taipei presenting mobility restrictions below 56 points, as shown in Table 2.

4.2. Global cities and pandemic gateways

A list of global cities, including their population, number of COVID-19 cases, associated national population and associated national COVID-19 cases is presented in Table 3. This table also presents the composite indexes, city rates, country rates and the calculated indicator Net Pandemic Ratio (NPR), expressing the pandemic infection comparison between cities and countries. The resulting dataset is composed of 53 cities\(^3\) from 33 different countries. About 76% of the countries had just one city on the list, while 18% had two cities. The exceptions are the United States with 11 cities, followed by Germany with five, and China with three cities.

The values listed in column “NPR” of Table 3 were calculated using a formula which yields the pandemic magnitude of each city to express the percent change between City COVID Ratio per capita and Country COVID Ratio per capita. If “NPR” results in a negative number, it means that on 9 April 2020, the city had fewer cumulative cases per capita than the national average and, consequently, a lower pandemic magnitude. Each positive value appearing in column “NPR” confirms our hypothesis for that specific city. In other words, it indicates that the rate of COVID-19 cases per capita in that city is higher than the rate found in that country. Sources for COVID-19 and population data of each city and country are elaborated in Appendices 1 and 2, including the reference year for population data.

As shown in Table 4, among the 55 global cities in Table 1, 75% (excluding Singapore and Taipei) presented higher COVID-19 rates per capita than their respective countries after the first 100 days of the pandemic. This reveals evidence of a correlation between being a global city and the chances of being a “pandemic gateway” and confirms our hypothesis for the global cities data set as a whole. The finding that 75% of the global cities included in our sample had higher rates of COVID-19 per capita than their respective countries, supports our hypothesis that they were gateways for the transmission of novel coronavirus. Identifying this strong relationship offers an important insight into understanding how hypermobility enabled COVID-19 to spread so far and wide within such a short time.

Even considering the particularities of each city’s local health agency in developing a COVID-19 pandemic response, most cities tended to follow the guidelines developed at higher government levels, especially concerning travel restrictions, border closures and social distancing measures. These means for managing the pandemic support our methodology by facilitating comparison of both cities and countries as two entities in a shared public health context, making it possible to observe

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\(^1\) Data was not available for three countries – Sweden, Denmark, and Taiwan.

\(^2\) Disaggregated data from Taiwan was not available.

\(^3\) Taipei and Singapore were excluded.
speed and severity with which the novel coronavirus spread through it. By Taylor et al. (2002) and discussed in Section 3.1 above, our findings pandemic gateways during the first 100 days of the pandemic. More -

Pandemic descriptive statistics by city and country.

Table 3

| Country  | City          | City population | City COVID-19 cases | City COVID ratio per capta | City COVID-19 per capta | Country COVID-19 cases | Country COVID ratio per capta | NPR |
|----------|---------------|-----------------|---------------------|---------------------------|-------------------------|-------------------------|-------------------------------|-----|
| London   | England       | 8,866,541       | 18,085              | 0.0204                    | 55,977,200              | 54,554                  | 0.00097                        | 109.3% |
| Paris    | France        | 12,174,680      | 26,543              | 0.0218                    | 66,361,587              | 82,048                  | 0.00124                        | 76.3% |
| New York | United States | 8,336,817       | 112,940             | 0.0135                    | 328,239,523             | 432,132                 | 0.00132                        | 929.0% |
| Tokyo    | Japan         | 13,921,000      | 1519                | 0.0011                    | 126,167,000             | 4768                    | 0.00004                        | 188.7% |
| Chicago  | United States | 2,693,976       | 8984                | 0.0033                    | 328,239,523             | 432,132                 | 0.00132                        | 187.1% |
| Frankfurt| Germany       | 746,878         | 794                 | 0.00106                   | 82,792,351              | 108,202                 | 0.00131                        | 18.7%  |
| Hong Kong| China         | 748,640         | 973                 | 0.00130                   | 1,336,210,000           | 15,067                  | 0.00001                        | 11426.2% |
| Los Angeles| United States| 10,039,107     | 12,178              | 0.00121                   | 328,239,523             | 432,132                 | 0.00132                        | -7.9%  |
| Milan    | Italy         | 1,366,180       | 12,479              | 0.00913                   | 60,463,973              | 139,422                 | 0.00023                        | 286.3% |
| Singapore| Singapore     | 5,703,569       | 1623                | 0.00028                   | 5,703,569               | 1623                    | 0.00028                        | 0.0%   |
| San Francisco| United States| 881,549        | 974                 | 0.00110                   | 328,239,523             | 432,132                 | 0.00132                        | -16.1% |
| Sydney   | Australia      | 5,312,163       | 1850                | 0.00033                   | 25,464,116              | 6052                    | 0.00024                        | 46.5%  |
| Toronto  | Canada        | 2,731,571       | 3203                | 0.00117                   | 35,151,728              | 19,274                  | 0.00055                        | 113.9% |
| Zurich   | Switzerland   | 409,241         | 2897                | 0.00708                   | 8,684,130               | 22,710                  | 0.00268                        | 164.5% |
| Brussels | Belgium       | 1,205,492       | 3164                | 0.00262                   | 11,398,589              | 28,235                  | 0.00248                        | 6.0%   |
| Madrid   | Spain         | 3,223,334       | 43,877              | 0.01361                   | 46,658,447              | 158,935                 | 0.0341                         | 299.6% |
| Mexico City | Mexico      | 8,985,339       | 1470                | 0.00196                   | 119,938,473             | 3181                    | 0.0003                         | 516.8% |
| Sao Paulo| Brazil        | 12,252,023      | 5832                | 0.00048                   | 210,147,125             | 15,927                  | 0.00008                        | 528.1% |
| Moscow   | Russia        | 11,514,330      | 6390                | 0.00055                   | 141,914,509             | 8672                    | 0.00006                        | 808.2% |
| Seoul    | South Korea   | 9,673,925       | 590                 | 0.00060                   | 51,629,512              | 10,423                  | 0.00020                        | -69.8% |
| Amsterdam| Netherlands   | 960,402         | 1004                | 0.00105                   | 16,979,120              | 20,549                  | 0.00121                        | -13.6% |
| Boston   | United States | 692,600         | 2812                | 0.00406                   | 328,239,523             | 432,132                 | 0.00132                        | 208.4% |
| Caracas  | Venezuela     | 1,943,901       | 28                  | 0.00001                   | 27,227,930              | 167                    | 0.00001                        | 134.8% |
| Dallas   | United States | 2,635,516       | 1432                | 0.00054                   | 328,239,523             | 432,132                 | 0.00132                        | -58.7% |
| Düsseldorf| Germany      | 617,280         | 740                 | 0.01200                   | 82,792,351              | 108,202                 | 0.00131                        | -8.3%  |
| Geneva   | Switzerland   | 200,548         | 4342                | 0.02165                   | 8,484,130               | 22,710                  | 0.00268                        | 708.8% |
| Houston  | United States | 4,713,325       | 2341                | 0.00050                   | 328,239,523             | 432,132                 | 0.00132                        | -62.3% |
| Jakarta  | Indonesia     | 9,640,400       | 1314                | 0.00185                   | 238,518,800             | 2956                    | 0.00001                        | 999.8% |
| Johannesburg | South Africa | 12,272,263   | 795                 | 0.00006                   | 51,729,512              | 1845                    | 0.00014                        | 81.8%  |
| Melbourne| Australia     | 5,078,193       | 992                 | 0.00200                   | 25,464,116              | 6052                    | 0.00024                        | -17.8% |
| Osaka    | Japan         | 8,809,000       | 616                 | 0.00006                   | 126,167,000             | 4768                    | 0.00004                        | 85.0%  |
| Prague   | Czech         | 1,324,277       | 1399                | 0.00106                   | 10,649,800              | 5312                    | 0.00050                        | 111.8% |

* Cities are ordered according their global city values on the GaWC ranking as illustrated in Table 1.

The speed, scale, and magnitude of pandemic diffusion among each paired city-country analysis.

Our results indicate a pattern of global city predominance as pandemic gateways during the first 100 days of the pandemic. Moreover, when cities are grouped according to the GaWC ranking developed by Taylor et al. (2002) and discussed in Section 3.1 above, our findings reveal that a city’s score in the global city ranking is correlated with the speed and severity with which the novel coronavirus spread through it. The same correlation trend observed between the GaWC ranking and the Global Direct Reach indicator discussed in our analysis of hypermobility (Section 4.1). is also found between the GaWC ranking and the group’s NPR infection indicators supported by three indicators of statistical distribution in our global city sample: the Overall Median, Overall Average, and Lowest Value of infection ratios in each of the three global city classification cohorts. The trend shows three distinct tiers of infection rates, represented by the “NPR” figures, among Alpha, Beta and Gamma cities, with the highest figures in the Alpha group and the lowest ones in the Gamma group, as observed in Table 4 and illustrated in Fig. 3.
4.3. Effects of the global cities hierarchy on the spread of COVID-19

To better explain the relationship between the pandemic’s diffusion through global cities and the GaWC index, we developed a table that highlights the dispersal rate from a global city to its national community on 9 April 2020. In Table 5, we selected the city with the highest GaWC index score for each respective country. This led to a grouping of 31 global cities, presented in Table 5, where 90% of the cities met the criteria for gateways in the COVID-19 pandemic, showing higher infection rates than their respective countries, expressed through a positive value of the Net Pandemic Ratio (NPR) indicator. The only exceptions were Frankfurt, Amsterdam, and Seoul, the first and the second with results very close to their countries’ average, 18.7% and 13.6%, respectively. Seoul stood out in the dataset with a striking 69.8% in relation to South Korea’s average. However, even with distinct diffusion patterns, Germany and South Korea saw their first COVID-19 case imported by air directly from China to one of their global cities (Bömer et al., 2020; Dighe et al., 2020). Moreover, the initial outbreak in Seoul presented a complex association with a local transmission cluster among members of a religious group. These three global city outliers clearly deserve further examination to identify why they did not function as pandemic gateways in early 2020.

The higher proportion of cities in Table 5 that have a positive NPR is also associated with a visible increase in the International Ratio and Global Direct Reach indicators’ average value. The International Ratio average rises from 0.50 to 0.60 when only the highest GaWC index score city in each country is considered, and the Global Direct Reach grows from 62 countries on average to 67 countries for the same comparison. These two findings add further evidence to demonstrate the connection between hypermobility, the GaWC ranking and a city’s function as a pandemic gateway in early 2020.

5. Conclusion & recommendations

Our analysis has demonstrated that a large majority of global cities followed a common pattern in the first wave of diffusion of the novel coronavirus pandemic during 2020. These global cities served as the gateway for COVID-19 to be spread into their respective countries. Drawing on a temporal analysis of 100 days after the first reported case on December 31, 2019, we have shown that 75% of the global cities from Table 3 were more affected than their respective countries on average. This tendency grows to 90% when the cities identified in Table 3 are subdivided into a compilation of the top ranked world city within each nation, as shown in Table 5. We found a direct relationship between globalization and pandemic gateways as demonstrated in Table 5.

We thus conclude that the link between global cities, and the flow of goods and people, both enabled and accelerated by hypermobility, was a significant element of how COVID-19 spread across the globe during the pandemic’s first wave in 2020.

Table 4

| Global city group | Sample size | Excluded cities | Comparison to country’s COVID ratios | NPR overall average | NPR overall median | NPR lowest value |
|-------------------|-------------|-----------------|-------------------------------------|---------------------|-------------------|------------------|
|                   |             |                 | Above (NPR > 0%) Below (NPR < 0%)   |                     |                   |                  |
| Alpha             | 10          | 1               | 7 2% 1518% 153% −19%                |                     |                   |                  |
| Beta              | 10          | 0               | 8 20% 240% 139% −70%                |                     |                   |                  |
| Gamma             | 35          | 1               | 25 9% 155% 83% −77%                 |                     |                   |                  |
| Total             | 55          | 2               | 40 13% 403% 111% −77%               |                     |                   |                  |

a Excluded cities are Singapore in Alpha Group and Taipei in Gamma. Source: Table 3.

4 Singapore and Taipei were excluded because of a lack of data.
direct contributor to pandemic diffusion in many countries, in ways that differ from the flows of capital and information between global cities.

Questions about what this pandemic can reveal about the future of globalization and global cities must remain a research focus well beyond the initial wave of pandemic diffusion, since the role of global cities is likely to evolve through different stages of the pandemic. A definitive answer of the complete role of global cities in the pandemic, can only be forthcoming when this disruptive event is clearly behind us.

Writing about the Ebola outbreak in 2016, Hoffman (2016: 30) asked: “How many people must die from pandemics before the world learns?” He went on to suggest that Ebola could teach the world three important lessons. The first lesson is that properly supported public interventions can stop the spread of viruses early on, even in this age of hypermobility and intercontinental travel and even after a virus has spread internationally. The second is the need to invest in research and development for new technologies and strategies to prepare us to better deal with future outbreaks. And his third finding offers a critique about the weakness of our global health agencies and identifies how they must be reformed (Hoffman, 2016). While his assessment addresses part of what should be done and how, our research adds a new focus on the places to advance such an agenda.

We suggest that whatever dynamic and configuration of globalization will emerge from this pandemic an important place to manage its impacts is one significant point of inflection in the trajectory of a global public health challenge that demands many more layers of understanding for its comprehensive management. Obtaining disaggregated airline data could advance insight by comparing the intercity volume of international direct flights between global cities over a more extended period to evaluate the temporal relationship between COVID-19 transmissions, globalization, hypermobility and cities.

To accomplish such reform, the world will need better information sources regarding pandemic effects within and between global cities. For proper tracking and the ability to understand the relation between globalization, hypermobility and cities, international agencies must invest in analytical infrastructure and data architecture and focus them on global cities. Developing a comprehensive and consistent set of socio-spatial data shared between the United Nations and the World Health Organization, to assemble comparable information at different scales (e.g., cities, metropolitan areas, urban agglomerations, provinces, states, and nations), would be important to support researchers in better understanding the evolution of this pandemic and preventing a future diffusion of the contagion that hypermobility spread quickly and widely during early 2020.

Even when global cities served as Pandemic Gateways, it should not be inferred from our findings that COVID-19 was a problem caused by these nodes in the network of exchange and interaction. What we have identified is one significant point of inflection in the trajectory of a global public health challenge that demands many more layers of understanding for its comprehensive management. Obtaining disaggregated airline data could advance insight by comparing the intercity volume of international direct flights between global cities over a more extended period to evaluate the temporal relationship between COVID-19 transmissions, globalization, and hypermobility. Domestic intercity mobility data could also make an important contribution to study local transmissions by illuminating the effects of different sizes and densities in pandemic gateway functions and supporting efforts to forecast the spread of infections over time.

Finally, the three outlier pandemic gateway cities that were identified in Table 5, Frankfurt, Amsterdam, and Seoul, deserve a deeper examination of the reasons why they differ from the other 90% of cities analysed in Table 5. One hypothesis deserving consideration is that those cities’ mobility patterns differed from other global cities in important ways (e.g., serving as a transit point in global aviation networks, with more ongoing connections than originating and destination traffic). Or it could be that contagion in their respective countries

**Table 5**
Pandemic and hypermobility magnitudes versus the GaWC score.

| Cities          | Country     | GaWC score | International ratio | Global direct reach | NPR (% of cities with NPR >0%) |
|-----------------|-------------|------------|---------------------|---------------------|-------------------------------|
| London          | England     | 12         | 0.91                | 119                 | 109.3%                        |
| Paris           | France      | 12         | 0.76                | 127                 | 76.3%                         |
| New York        | United States | 12       | 0.23                | 96                  | 929.0%                        |
| Tokyo           | Japan       | 12         | 0.30                | 57                  | 188.7%                        |
| Frankfurt       | Germany     | 10         | 0.88                | 125                 | 18.7%                         |
| Hong Kong       | China       | 10         | 1.00                | 60                  | 11426.2%                      |
| Milan           | Italy       | 10         | 0.63                | 83                  | 296.3%                        |
| Sydney          | Australia   | 9          | 0.29                | 34                  | 46.5%                         |
| Toronto         | Canada      | 9          | 0.49                | 74                  | 112.9%                        |
| Zurich          | Switzerland | 9          | 0.97                | 80                  | 164.5%                        |
| Brussels        | Belgium     | 8          | 1.00                | 101                 | 6.0%                          |
| Madrid          | Spain       | 8          | 0.61                | 81                  | 299.6%                        |
| Mexico City     | Mexico      | 8          | 0.27                | 33                  | 516.8%                        |
| Sao Paulo       | Brazil      | 8          | 0.12                | 41                  | 528.1%                        |
| Moscow          | Russia      | 7          | 0.28                | 88                  | 800.8%                        |
| Seoul           | South Korea | 7          | 0.52                | 58                  | −69.8%                        |
| Amsterdam       | Netherlands | 6          | 1.00                | 98                  | −13.6%                        |
| Caracas         | Venezuela   | 6          | 0.85                | 24                  | 134.8%                        |
| Jakarta         | Indonesia   | 6          | 0.13                | 29                  | 999.8%                        |
| Johannesburg    | South Africa | 6         | 0.38                | 55                  | 81.8%                         |
| Prague          | Czech Republic | 6       | 0.99                | 49                  | 111.8%                        |
| Santiago        | Chile       | 6          | 0.37                | 27                  | 42.2%                         |
| Bangkok         | Thailand    | 5          | 0.38                | 64                  | 325.6%                        |
| Stockholm       | Sweden      | 5          | 0.65                | 62                  | 380.9%                        |
| Warsaw          | Poland      | 5          | 0.81                | 72                  | 450.7%                        |
| Buenos Aires    | Argentina   | 4          | 0.46                | 33                  | 336.1%                        |
| Budapest        | Hungary     | 4          | 1.00                | 48                  | 144.1%                        |
| Copenhagen      | Denmark     | 4          | 0.84                | 65                  | 57.8%                         |
| Istanbul        | Turkey      | 4          | 0.55                | 116                 | 24.3%                         |
| Kuala Lumpur    | Malaysia    | 4          | 0.51                | 50                  | 208.3%                        |
| Manila          | Philippines | 4          | 0.47                | 40                  | 459.7%                        |

Average          | 0.60        | 67         | 635.1               | 90.32%              |
occurred through viral introduction from neighboring countries with other pandemic gateways. Another hypothesis is that some other features of these cities managed the pandemic particularly effectively, like strong public health measures that kept transmission rates lower than other pandemic gateway cities that were not outliers. A fourth hypothesis is that there were some features of the national geography and society that encouraged the rapid spread of the virus outside of the pandemic gateway, like the example from the religious group in South Korea that had a significant pandemic cluster outside Seoul.

Our assessment confirms the hypothesis that globalization and hypermobility were related to the transmission of COVID-19 in the first pandemic wave of 2020, through a positive correlation with the GaWC ranking of cities (Taylor et al., 2002). The majority of these global cities turned out to be the gateway by which COVID-19 was introduced to their respective countries. Therefore, recognizing this pandemic gateway function of global cities appears to be essential to better understanding the effects of hypermobility, global networks, and disease transmission in the years, and pandemics, to come.

CRediT authorship contribution statement

Leandro da Silva Corrêa: Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft, Writing – review & editing. Anthony Perl: Conceptualization, Supervision, Project administration, Validation, Writing – original draft, Writing – review & editing.

Declaration of competing interest

None.

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Appendix A

Appendix 1

Population sources.

| City              | Country  | Year | ref                              | Source population   |
|-------------------|----------|------|----------------------------------|---------------------|
| Amsterdam         | Netherlands | 2016 | https://ec.europa.eu/         |                     |
| Atlanta           | United States | 2019 | https://www.census.gov/        |                     |
| Bangkok           | Thailand | 2010 | http://web.mso.go.th          |                     |
| Barcelona         | Spain    | 2018 | https://ec.europa.eu/         |                     |
| Beijing           | China    | 2018 | http://www.stats.gov.cn      |                     |
| Berlin            | Germany  | 2018 | https://ec.europa.eu/         |                     |
| Boston            | United States | 2019 | https://www.census.gov/      |                     |
| Brussels          | Belgium  | 2018 | https://ec.europa.eu/         |                     |
| Budapest          | Hungary  | 2018 | https://ec.europa.eu/         |                     |
| Buenos Aires      | Argentine | 2010 | https://www.indec.gob.ar    |                     |
| Caracas           | Venezuela | 2011 | http://www.ine.gov.ve       |                     |
| Chicago           | United States | 2019 | https://www.census.gov/      |                     |
| Copenhagen        | Denmark  | 2019 | wwww.dst.dk                  |                     |
| Dallas            | United States | 2019 | https://www.census.gov/      |                     |
| Düsseldorf        | Germany  | 2018 | https://ec.europa.eu/         |                     |
| Frankfurt         | Germany  | 2018 | https://ec.europa.eu/         |                     |
| Geneva            | Switzerland | 2018 | https://ec.europa.eu/        |                     |
| Hamburg           | Germany  | 2018 | https://ec.europa.eu/         |                     |
| Hong Kong         | China/Hong Kong | 2018 | https://www.censtatd.gov.hk |                     |
| Houston           | United States | 2019 | https://www.census.gov/      |                     |
| Istanbul          | Turkey   | 2018 | http://www.turkstat.gov.tr/  |                     |
| Jakarta           | Indonesia | 2010 | https://www.bps.go.id       |                     |
| Johannesburg      | South Africa | 2011 | http://www.statsa.gov.za     |                     |
| Kuala Lumpur      | Malaysia | 2018 | https://www.dosm.gov.my      |                     |
| London            | England  | 2018 | https://www.ons.gov.uk/      |                     |
| Los Angeles       | United States | 2019 | https://www.census.gov/      |                     |
| Madrid            | Spain    | 2018 | https://ec.europa.eu/         |                     |
| Manila            | Philippines | 2019 | https://psa.gov.ph/          |                     |
| Melbourne         | Australia | 2019 | https://www.abs.gov.au      |                     |
| Mexico City       | Mexico   | 2015 | http://en.www.inegi.org.mx  |                     |
| Miami             | United States | 2019 | https://www.census.gov/      |                     |
| Milan             | Italy    | 2018 | https://ec.europa.eu/         |                     |
| Minneapolis       | United States | 2019 | https://www.census.gov/     |                     |
| Montreal          | Canada   | 2016 | https://www.statcan.gc.ca    |                     |
| Moscow            | Russia   | 2010 | https://eng.gks.ru/eurstat |                     |
| Munich            | Germany  | 2018 | https://ec.europa.eu/         |                     |
| New York          | United States | 2019 | https://www.census.gov/      |                     |
| Osaka             | Japan    | 2019 | https://www.e-stat.go.jp   |                     |
| Paris             | France   | 2016 | https://ec.europa.eu/         |                     |
| Prague            | Czech Republic | 2019 | https://ec.europa.eu/       |                     |
| Rome              | Italy    | 2018 | https://ec.europa.eu/        |                     |
| San Francisco     | United States | 2019 | https://www.census.gov/     |                     |
| Santiago          | Chile    | 2017 | https://www.bcn.cl/         |                     |

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Appendix 1 (continued)

| City       | Country          | Year | ref                          | Source population                                      |
|------------|------------------|------|------------------------------|--------------------------------------------------------|
| Sao Paulo  | Brazil            | 2019 |                             | https://www.ibge.gov.br/                               |
| Seoul      | South Korea       | 2018 |                             | http://kosis.kr                                        |
| Shanghai   | China             | 2018 |                             | http://www.stats.gov.cn                                |
| Singapore  | Singapore         | 2019 |                             | https://www.singstat.gov.sg                             |
| Stockholm  | Sweden            | 2018 |                             | https://ec.europa.eu                                      |
| Sydney     | Australia         | 2019 |                             | https://www.abs.gov.au                                  |
| Tokyo      | Japan             | 2019 |                             | https://www.e-stat.go.jp                                |
| Toronto    | Canada            | 2016 |                             | https://www.statcan.gc.ca                                |
| Warsaw     | Poland            | 2014 |                             | https://ec.europa.eu                                     |
| Washington | United States     | 2019 |                             | https://www.census.gov/                                  |
| Zurich     | Switzerland       | 2018 |                             | https://ec.europa.eu                                      |

Appendix 2

COVID-19 sources for cities.

| City            | Source                                      | Link to source data                                      |
|-----------------|---------------------------------------------|----------------------------------------------------------|
| Amsterdam       | Corona Locator Netherlands                  | https://bddataplan.nl/corona/                             |
| Atlanta         | CDC USA Gov. - Fulton County                | https://unafacts.org/visualizations/coronavirus-COVID-19-spread-map/ |
| Bangkok         | WorkPoint News Thailand                     | https://covid19.workpointnews.com/                        |
| Barcelona       | Barcelona Government                        | https://dades.ajuntament.barcelona.cat/seguiement-covid19-bcn/ |
| Beijing         | Johns Hopkins University                    | https://github.com/CSSEGISandData-COVID-19              |
| Berlin          | Berlin Government                           | https://www.berlin.de/corona/fallstatistik/             |
| Boston          | City of Boston Government                   | https://dashboard.cityofboston.gov/https://showGuest/Access/Enabled/views/COVID-19/Dashboard1?showAppPlanner=false&displayco
|                |                                             | unit=n&showVizHome=&origin=viz_share_link&isGuestRedirectFromVizportal=y&embed=y |
| Brussels        | Scientano - COVID19                         | https://covid-statistics.jrc.ec.europa.eu/Home/Dashboard?country=HUN |
| Budapest        | European Commission – ECML                  |                                                           |
| Buenos Aires    | Buenos Aires City Government                | https://www.buenosaires.gob.ar/coronavirus/noticias/actualizacion-de-los-casos-de-coronavirus-en-la-ciudad-buenos-aires |
| Caracas         | TalCual Website                             | https://talcualdigital.com/casos-confirmados-de-coronavirus-aumentan-a-171-en-venezuela/ |
| Chicago         | City of Chicago Government                  | https://www.chicago.gov/city/en/sites/COVID-19/home/covid-dashboard.html |
| Copenhagen      | Statens Serum Institut                       | https://files.ssi.dk/Antal-covid19-tillaedler-per-kommune-10042020-2-ud79 |
| Dallas          | CDC USA Gov. - Dallas County                | https://unafacts.org/visualizations/coronavirus-COVID-19-spread-map/ |
| Düsseldorf      | COVID-19 Germany-GAE                        | https://github.com/jgehrcke/COVID-19-germany-gae/blob/master/cases-rito-by-agvs-crv  |
| Frankfurt       | COVID-19 Germany-GAE                        | https://github.com/jgehrcke/COVID-19-germany-gae/blob/master/cases-rito-by-agvs-crv  |
| Geneva          | Switzerland Government                      | https://COVID-19-schweiz.bagapps.ch/fr-2.html            |
| Hamburg         | COVID-19 Germany-GAE                        | https://github.com/jgehrcke/COVID-19-germany-gae/blob/master/cases-rito-by-agvs-crv  |
| Hong Kong       | Johns Hopkins University                    | https://github.com/CSSEGISandData-COVID-19              |
| Houston         | CDC USA Gov. - Harris County                | https://unafacts.org/visualizations/coronavirus-COVID-19-spread-map/ |
| Istanbul        | Local News - Health Min                     | https://balkaneu.com/turkey-60-of-total-cases-found-in-istanbul-601-outbreaks-amongst-health-workers/ |
| Jakarta         | Jakarta Government                          | https://covid19jia.org/provincial-breakdown             |
| Johannesburg   | WITS University                             | https://covid-statistics.jrc.ec.europa.eu/Home/Dashboard?country=HUN |
| Kuala Lumpur    | Malaysia Gov. - Dept. of Statistics         | https://nakddom.github.io/COVID-19                        |
| London          | UK Government                               | https://coronavirus.data.gov.uk/cases?areaType=region&areaName=London |
| Los Angeles     | Los Angeles County Public Health            | http://dashboard.publichealth.lacounty.gov/covid19_surveillance_dashboard/ |
| Madrid          | Spain Government – DSN                      | https://www.dsn.gob.es/au/actualidad/sala-prensa/coronavirus-COVID-19-09-abril-2020 |
| Manila          | Philippines Gov. - Dept. of Health           | https://www.doh.gov.ph/covid19tracker                   |
| Melbourne       | Victoria State Government                   | https://www.dhhs.vic.gov.au/coronavirus-update-victoria-9-april-2020 |
| Mexico City     | Mexico Government                           | https://coronavirus.gov.mx/datos/#DownZCSV               |
| Miami           | CDC USA Gov. - Miami-Dade County             | https://unafacts.org/visualizations/coronavirus-COVID-19-spread-map/ |
| Milan           | Protezione Civile, JIHU CSSE                | https://statistichecoronavirus.it/province-coronavirus-italia/milano/ |
| Minneapolis     | CDC USA Gov. - Hennepin County               | https://unafacts.org/visualizations/coronavirus-COVID-19-spread-map/ |
| Montreal        | University of Toronto                       | https://www.cbc.ca/news/canada/montreal/montreal-COVID-19-containment-1.5526534 |
| Moscow          | European Commission – ECML                  | https://covid-statistics.jrc.europa.eu/Home/Dashboard?country=HUN |
| Munich          | COVID-19 Germany-GAE                        | https://github.com/jgehrcke/COVID-19-germany-gae/blob/master/cases-rito-by-agvs-crv  |
| New York        | New York City Health Govern.                | https://www1.nyc.gov/site/doh/covid/covid-19-data-page   |
| Osaka           | The Japan Times                             | https://www.japantimes.co.jp/news/2020/04/09/national/science-health/tokyo-181-coronavirus-cases-record/#.Xy332y8Kjb0 |
| Paris           | Sante Publique France                       | https://www.santepubliquefrance.fr/recherche/#search=CVID%202019%20point%20epidemiologique&regions=Ile-de-Fran
|                |                                             | ce&sort=date                                             |

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Appendix 2 (continued)

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