Preliminary assessment of the International Spreading Risk Associated with the 2019 novel Coronavirus (2019-nCoV) outbreak in Wuhan City

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Introduction

Starting in December 2019, Chinese health authorities have been closely monitoring a cluster of pneumonia cases in the city of Wuhan, in Hubei Province. It has been determined that the pathogen causing the viral pneumonia among affected individuals is a new coronavirus (2019-nCoV)(1). As of January 17, 2020, 45 cases have been detected and confirmed in the region(2) with 3 additional cases detected and confirmed in Japan and Thailand(3; 4). The source of the outbreak is still unknown, however investigations have identified environmental samples that tested positive for 2019-nCoV at the Huanan Seafood Wholesale Market in Wuhan city. Some of the most recent cases did not report exposure to animal markets, thus suggesting that human-to-human transmission, although limited, is possible. Considering the potential international threat that an outbreak of a novel virus like this one poses to the world, in this report we provide a modeling analysis of the risk of dissemination of 2019-nCoV infections. By using the cases detected outside China, we also provide estimates of the potential outbreak size in Wuhan as of January 17th, 2020.

Results

Here we use a detailed individual based mobility model to estimate the extent of the outbreak and the risk of international dissemination on a longer time scale. Our model simulates the mobility of people across more than 3,300 subpopulations in about 190 countries/territories. Subpopulations are defined by the catchment area of major transportation hubs. The mo-

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Rank	International			Domestic		
	City	Country	Risk	City	Chinese Province	Risk
1	Bangkok	Thailand	0.014	Hong Kong*	Hong Kong*	0.066
2	Seoul	Korea, Rep.	0.006	Shanghai	Shanghai	0.057
3	Taipei	Taiwan*	0.006	Beijing	Beijing	0.051
4	Tokyo Narita	Japan	0.005	Kunming	Yunnan	0.039
5	Phuket	Thailand	0.004	Chengdu	Sichuan	0.036
6	Kota Kinabalu	Malaysia	0.004	Haikou	Hainan	0.036
7	Singapore	Singapore	0.004	Guangzhou	Guangdong	0.034
8	Kaohsiung	Taiwan*	0.003	Xiangyang	Hubei	0.030
9	Ho Chi Minh City	Vietnam	0.003	Xiamen	Fujian	0.028
10	Osaka	Japan	0.002	Jiujiang	Jiangxi	0.025
11	Sydney (AU)	Australia	0.002	Fuyang	Anhui	0.024
12	Denpasar	Indonesia	0.002	Chongqing	Chongqing	0.024
13	Kuala Lumpur	Malaysia	0.002	Sanya	Hainan	0.024
14	Dubai	U.A.E.	0.002	Yichang	Hubei	0.023
15	London	United Kingdom	0.002	Shenyang	Liaoning	0.021

Table 1: Top 15 international and domestic destinations ranked according to their relative risk of case importation.*Estimated risks for Hong Kong and Taiwan do not account for the effects of the protests in Hong Kong (reduction in tourism to the area (5)) and travel restrictions between China and Taiwan since August 1st, 2019 (6).

bility among subpopulations integrates the mobility by global air travel (obtained from the International Air Transport Association and Official Airline Guide databases) and the short-scale mobility between adjacent subpopulations, which represents the daily commuting patterns of individuals (see Data & Methods).

Risk analysis

Based on the number of infected individuals detected in Wuhan (China) the model estimates two main quantities:

- Relative importation risk: for each destination Y, the model estimates the probability $P(Y)$ that a single infected individual travels from the index areas to that specific destination Y. In other words, given the occurrence of one exported case, $P(Y)$ is the probability that the disease carrier will appear in location Y, with respect to any other possible location.

- Exported cases: the model estimates the probability $P(n)$ of exporting a given number of cases n from the origin of the disease outbreak. To calculate the distribution P, the average time from exposure to symptoms onset/detection inability of traveling of infected individuals must be provided.

In Table 1, we provide the top 20 Chinese and international destinations ranked according to their relative importation risk. A full list is available using the interactive online dashboard[1].

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[1] `http://j.mp/2019-nCoV-2500-10days`

Catchment area population	Median Outbreak size	(95% CI)
10M	1,250	350-3,000
20M	2,500	700-5,900
30M	3,750	1,100-8,400

Table 2: Estimated median size of the outbreak for the different scenarios considered.

Outbreak size estimate

As of January 17, internationally, there have been three detected and confirmed cases: one in Japan (3) and two in Thailand(4). We assume that exposed individuals are potential travelers for an average time of $\tau_d = 10(7; 8)$ days before developing symptoms and being detected (an exponential distribution is assumed). We also assume the detection of all cases exported internationally with history of traveling from Wuhan (China). The effective population in the catchment area of Wuhan varies between 10 million, 20 million and 30 million if we consider the city, the metropolitan area and the population of the province closest to Wuhan airport, respectively (9). The mobility model can then be used to estimate the size of the outbreak in Wuhan given the number of internationally detected infected cases. Using an Approximate Bayesian (ABC) approach we use the model to generate the posterior distribution $P(\theta|D)$ of the size of the outbreak θ in Wuhan given the evidence D of three international exported cases (see Data & Methods section). Figure 1 shows the posterior probability of the outbreak size in Wuhan if we consider the an effective population of 20M individuals. In Table 2 we report the median and 95% credible interval by assuming three different scenarios for the catchment area population. A sensitivity analysis for τ_d in the range from 8 to 12 yields similar results. Similar results have been derived following a different methodology in (10).
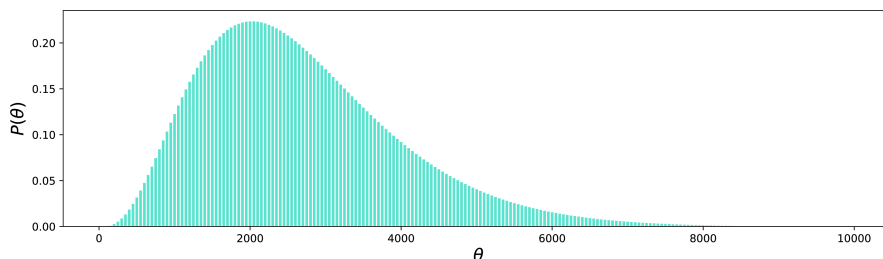

Figure 1: Posterior distribution for the probability of an outbreak of size θ in Wuhan given the evidence of 3 exported cases outside China. The effective catchment area is considered to be 20 million people.

Discussion

The model highlights the relative risk of observing 2019-nCoV cases for major urban areas in China and internationally. The model also provides an estimate of the size of the Wuhan outbreak as of January 17, 2020. This estimate suggests that there is likely a large number

of undetected/untested cases. It is important to stress that the lack of detailed data on the 2019-nCoV outbreak makes modeling approaches vulnerable to the assumptions and limitations about data and parameters. In particular, the presented preliminary assessment does not consider any human to human transmission and the local generation of cases outside of Wuhan. We assume that travel probabilities are homogeneous across all individuals in the catchment area of Wuhan city. This implies that the travel probability is independent of age, risk of exposure, and specific location within the catchment barea. The time from exposure to detection τ_d is unknown and it is approximated by considering the SARS and MERS Coronavirus epidemiology. Even given the above limitations we hope that this preliminary analysis of the Wuhan 2019-nCoV outbreak and the associated risk of international spread provided here may be useful to national and international agencies.

Data & Methods

Data. The airline transportation data used in the platform are based on origin-destination traffic flows from the Official Aviation Guide (OAG) and IATA databases. We use the average number of daily passengers traveling outside of Wuhan during the months December 2018, January 2019, and February 2019. Commuting flows are derived by the analysis and modeling of commuting data collected from the Offices of Statistics for 30 countries on 5 continents. The full dataset contains about 80 thousand administrative regions on five continents and over 5 million commuting flow connections between them (11). Population data are obtained from the high-resolution population database of the Gridded Population of the World project from the Socioeconomic Data and Application Center at Columbia University (`sedac.ciesin.columbia.edu`). The model considers geographical cells of 0.25° x 0.25°, corresponding to an approximately 25km x 25km square for cells along Earth's equator. Cells are then grouped into subpopulations defined by a Voronoi-like tessellation of the Earth's surface centered around major transportation hubs in different urban areas. The model includes over 3,300 subpopulations in roughly 200 different countries and territories (numbers vary by year).

Methods We estimate the probability of exporting infected individuals from sites affected by 2019-nCoV outbreak to other areas by individual based simulations of human mobility through the airline transportation network and daily commuting patterns. The Approximate Bayesian Computation (ABC) for the estimation of the posterior distribution of the outbreak is based on a sampling of the size of the outbreak θ ranging from 45 to 5,000 cases, with a uniform prior. This allows us to calculate the distribution $P(D)$ for the evidence D and for each outbreak size θ, the likelihood $P(D|\theta)$. The evidence D is the observation of the exportation of three 2019-nCoV cases, with a tolerance provided by the fact that no exact location on the exportation is imposed. From those distributions we can calculate the posterior probability $P(\theta|D)$ of interest.

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