RECOMMENDED CITATION

Shi S, Tanaka S, Ueno R, Gilmour S, Tanoue Y, Kawashima T, et al. Impact of travel restrictions on importation of novel coronavirus infection: An effective distance approach. [Submitted]. *Bull World Health Organ*. E-pub: 18 March 2020. doi: http://dx.doi.org/10.2471/BLT.20.255679

Impact of travel restrictions on importation of novel coronavirus infection: An effective distance approach

Authors: Shoi Shi[1], Shiori Tanaka[1,2], Ryo Ueno[3], Stuart Gilmour[4], Yuta Tanoue[5], Takayuki Kawashima[6], Shuhei Nomura[1,7], Hiroaki Miyata[7], Daisuke Yoneoka[1,4,7]

Affiliations

1: Graduate School of Medicine, The University of Tokyo, Tokyo, Japan

2: Epidemiology and Prevention Group, Center for Public Health Sciences, National Cancer Center, Tokyo, Japan

3: The Australian and New Zealand Intensive Care Research Centre, Melbourne, Australia

4: Graduate School of Public Health, St. Luke's International University, Tokyo, Japan

5: Institute for Business and Finance, Waseda University, Tokyo, Japan

6: Department of Mathematical and Computing Science, Tokyo Institute of Technology, Tokyo, Japan

7: Department of Health Policy and Management, School of Medicine, Keio University, Tokyo, Japan

(Submitted: 18 March 2020 – Published online: 18 March 2020)

Correspondence: Daisuke Yoneoka

OMURA Susumu & Mieko Memorial, St. Luke's Center for Clinical Academia, 5th Floor, 3-6-2 Tsukiji, Chuo-ku, Tokyo 104-0045 Japan

E-mail: daisuke.yoneoka@slcn.ac.jp

Word count (abstract): 250 words
Word count (main texts): 2680 words
Figure: 5
Table: 0
Supplementary figure: 0
Supplementary table: 2
Reference: 21

Abstract

Objectives

The international spread of COVID-19 infection has attracted global attention. We estimate potential risk reduction and geographical range of COVID-19 spread based on airline travel network data.

Methods

Passenger volume data for the global airline network and the time at which the first confirmed COVID-19 case was observed in each airport and country were extracted from publicly available data sources. A survival analysis technique in which the hazard function was a function of effective distance from Wuhan city in China was utilized to estimate the risk of importation of COVID-19 in each airport.

Findings

A total of 28 countries with imported cases were identified. Of these, 21 countries imported the COVID-19 before the travel restrictions and the other 7 countries imported it after the travel restriction. The arrival time ranged from 39 to 80 days since identification of the first case in Wuhan, China on 8th December 2019 was identified. Hypothetical scenario analyses indicated that both strategies of reducing global passenger volume and shutting down the top 10 hub airports would be equally effective in reducing the risk of importation of COVID-19, but the impact on the risk of importation of COVID-19 might be limited with almost zero median relative risk reduction.

Conclusion

Travel restrictions were not effective enough to prevent the global spread of COVID-19 in most of the airports. Our study highlights the need to strengthen local capacities for disease monitoring and control, rather than controlling the importation of COVID-19 at national borders via the airline network.

Introduction

As of 5 March 2020, 3,199 deaths out of 93,164 laboratory-confirmed infectious cases of novel coronavirus (COVID-19) were reported [1, 2]. The rapid growth of cases in Wuhan and internationally, including other Asian countries, the United States and Europe was accelerated by the global human movements [1, 3, 4]. Most of the current strategies to reduce the risk of COVID-19 transmission are based on controlling the human-human interactions, including case isolation, tracking the contact of patients, and entry/exit screening at national borders.

International airline travelers departing from China could unintentionally transport a novel coronavirus all over the world. As of 30 January 2020, the Emergency Committee convened by the World Health Organization (WHO) under the International Health Regulations (IHR) described the unfolding outbreak as a Public Health Emergency of International Concern and proposed several recommendations to strengthen the monitoring and surveillance of the virus at the international level. The Committee did not recommend any restrictions on global travel or trade for any countries, including China, based on the available information at the moment [5]. Nevertheless, as with the previous case of infectious epidemics such as Ebola virus disease (EVD), severe acute respiratory syndrome (SARS) and influenza H1N1-2009, a considerable number of countries at risk have adopted national policy to respond the importation of COVID-19 at their national borders. However, it is still unclear how travel restrictions contribute to control of COVID-19 transmission through the global airline network [4].

Responding to the rapid dissemination of emerging infectious diseases fueled the by airline travel network, several mathematical modeling techniques have been developed [6-11]. Colizza et al. (2007) proposed a new stochastic meta-population model that incorporates travel records and census data in 220 countries to examine a prediction accuracy for the global spread of SARS [11]. A large-scale simulation study estimated the impact of travel restrictions on the delay effect of the EVD epidemic, demonstrating that the restrictions delayed EVD outbreaks for approximately 30 days in the WHO Regional Office for Africa (AFRO) countries [9]. Otsuki and Nishiura (2016), whose methodological approach we followed, estimated the reductions in absolute risk (less than 1%) and relative risk (about 20%) due to the travel restrictions, concluding that the restrictions were not effective enough to prevent the global spread of EVD [10]. An overall review of the relationship between global transportation network and spread of infectious diseases can be found in [12].

In this study, we evaluated the effect of imposed travel restrictions on the prevention of COVID-19 transmission, using a hazard-based model and the concept of effective distance based on travel network data to explore patterns of domestic and international population movement from Wuhan, in China. Our findings on travel patterns could contribute to tailoring public health interventions, especially for controlling the risk at national borders.

Methods

Dataset

The dates of starting travel restriction and first onset of COVID-19 case for each country were extracted from publicly available secondary data sources [13, 14]. We included 200 countries. Two authors (DY and SS) independently checked its validity against official announcements from each government. The travel restrictions included (i) *entry or exit bans*, defined as general restriction on the ability of people to depart from their country for travel to china or the ability of foreigners to enter a country after traveling from or transiting via China, (ii) *visa restrictions*, defined as total or partial visa suspensions for travelers from China, and (iii) *flight suspensions*, defined as governmental bans on flights to or from China [15, 16].

To construct the airline transportation network, we used the ADS-B exchange data (downloaded from https://history.adsbexchange.com/downloads/samples/), a graph of travel behavior consisting of 1773 nodes and 23,505 edges. In the network diagram, each node represents an airport and each edge represents passenger volume (PV) on a direct flight between two nodes. The PV on a certain flight was estimated as the reported number of seats of the airplane multiplied by 0.7 [10, 17].

Effective distance

To examine the impact of airline network restriction on 2019-nCoV transmission, an *effective distance*, which was introduced by Brockmann and Helbing (2013) [18], was calculated from the network diagram. The effective distance is calculated based on the adjacency matrix of the network diagram and defined as the minimum distance between each node, incorporating the information of path length and the degree of each nodes. Previous studies showed the preferable prediction ability of the distance for the arrival time (i.e., the time during emergence to importation of infectious diseases): for example, Brockmann and Helbing (2013) tested its performance in predicting the global spread of SARS and influenza H1N1-2009 [18], Nah et al. (2016) used the distance for the real time forecasting of Middle East Respiratory Syndrome (MERS) and Zika virus [17, 19], and Otsuki and Nishiura (2016) used it to clarify the impact of the travel restriction for EVD [10].

The effective distance, d_{ij}, between the ith airport in the jth country and Wuhan airport is defined as the minimum of all possible effective path lengths. The effective path length from Wuhan city to the ith airport with a sequence of $l-1$ transit airports $\{a_{wuhan}, a_1, \dots, a_{l-1}\}$ is given by

$$m_l^{(i,j)} = l - log\prod_{k=1}^{l-1} P_{k+1,k},$$

where $P_{l,m}$ denotes the conditional (transition) probability that an individual that left the lth to the mth airport. This transition probability was estimated as $P_{l,m} = \frac{w_{lm}}{\sum_n w_{ln}}$, where w_{lm} is the PV that moved from the lth to the mth airport. Lastly, since the network structure and its associated effective distance changed after the travel restrictions by each country, we assumed that, as with the previous study's settings in [9, 10], 75% of corresponding (direct) flights were canceled during a travel restriction. The effective distance before and after the travel restrictions are denoted by d_{ij}^{0} and d_{ij}^{1}, respectively.

Modeling strategy: hazard-based model with effective distance

We modeled the risk of importing COVID-19 estimating survival probability. Let T be a random (continuous) variable indicating the time from the first onset in Wuhan city to importation in the *i*th airport. Also define the survival probability as $F(t) = P(T < t)$ with the probability density function (pdf) $f(t)$. $t = 0$ is the time of observation of the first case of COVID-19 in Wuhan city (i.e., 8 December 2019). The hazard function for importation of COVID-19 for the *i*th airport in the *j*th country is modeled as

$$\lambda_{ij} = \frac{f_{ij}(t)}{F_{ij}(t)} = \exp(\frac{\beta_j}{d_{ij}}),$$

where β_j is a (country-specific) parameter of interest. This formulation allows the median time of importation to be proportional to the effective distance d_{ij}, which is consistent with Brockmann and Helbing (2013) and Otsuki and Nishiura (2016) [10, 18]. Using this hazard function, the pdf of survival time can be modeled as $f_{ij}(t) = \lambda_{ij} \exp\left(-\int_0^t \lambda_{ij} ds\right) = \lambda_{ij} \exp\left(-t_{ij}\right)$.

A total of 200 countries were categorized into three separate groups: (A) countries that imported COVID-19 before travel restriction, (B) countries that imported COVID-19 after travel restriction, and (C) countries that did not import any COVID-19 cases until the end of study. The likelihood of (A) is given by

$$L_A = \prod_{i \in A} \lambda_{ij}^{0} \exp\left(-\lambda_{ij}^{0} t_{ij}\right),$$

where λ_{ij}^{0} indicates the hazard function calculated based on the effective distance before the travel restriction d_{ij}^{0}. Similarly, the likelihood of (B) is given by

$$L_B = \prod_{i \in B} \lambda_{ij}^{1} \exp\{-\lambda_{ij}^{1}(t_{ij} - t_s)\}\exp(-\lambda_{ij}^{0} t_s),$$

where λ_{ij}^{1} indicates the hazard function calculated based on the effective distance after the travel restriction d_{ij}^{0} and t_s is the 30 January 2020, the day on which WHO described the outbreak as a Public Health Emergency of International Concern. This is the joint likelihood of the probability of escaping from importation for t_s days before travel restriction and the probability of importing COVID-19 during $t_{ij} - t_s$. The likelihood of (C) is given by

$$L_c = \prod_{i \in c} \exp\{-\lambda_{ij}^{1}(t_l - t_s)\}\exp(-\lambda_{ij}^{0} t_s),$$

where t_l is the end of this study period (i.e., 26th February, 2020). This is the joint likelihood of the probability of escaping from importation of COVID-19 for t_s days before the travel restriction and for $t_l - t_s$ days after the travel restriction. Lastly, the total likelihood is given by

$$L = L_A L_B L_C$$

and the maximum likelihood approach was used to estimate βs. The 95% confidence intervals were calculated based on the empirical fisher information matrix.

Estimate of absolute/relative risk reduction: Hypothetical scenarios approach

The effect of travel restrictions on risk was calculated based on the cumulative risk of importation by comparing observed and hypothetical scenarios. Since the hazard is fixed over the time period, the cumulative risk of importation for *i*th airport in *j*th country in the Observed scenario is given by

$$R_{ij}^{O} = 1 - \exp\{-\lambda_{ij}^{0} t_s - \lambda_{ij}^{1}(t_l - t_s)\}.$$

In contrast, we assumed three hypothetical scenarios: (H1) no travel restriction had taken place, (H2) same travel restriction had taken place but 25% or 50% of corresponding flight were canceled instead of the current assumption of 75%, and (H3) the top 10 nodes with the highest degrees that did not implement the travel restriction were assumed to restrict the travel (i.e., the top 10 highest PV airports that were not listed in the list of countries with the travel restriction). Scenario H3 represented the hypothetical situation where the high impact airport (or the associated country) on the network implemented the travel restriction. The cumulative risk in (H1) is given by

$$R_{ij}^{H_1} = 1 - \exp(-\lambda_{ij}^{0} t_l).$$

In a similar way to R_{ij}^{O}, the cumulative risks in (H2) and (H3) are given by $R_{ij}^{H_h} = 1 - \exp\left\{-\lambda_{ij}^{0,H_h} t_s - \lambda_{ij}^{1,H_h}(t_l - t_s)\right\}$, where $h = 2, 3$ indicates scenarios (H2) and (H3), respectively, and λ_{ij}^{0,H_h} and λ_{ij}^{1,H_h} are associated hazard function based on each scenario assumptions. Lastly, we estimated the absolute and relative risk reduction as follows:

$$\text{Absolute risk reduction} = R_{ij}^{O} - R_{ij}^{H}, \text{ and}$$

$$\text{Relative risk reduction } (\textit{relrisk}) = 1 - R_{ij}^{H}/R_{ij}^{O},$$

where the absolute risk reduction measures the absolute difference of risk between Observed and the hypothetical scenarios, and the relative risk reduction measures the proportion of risk reduction between Observed and the hypothetical scenarios.

Results

Figures 1 and 2 show the entire flight network and that only from China (especially, Wuhan city) before the travel restriction. The list of countries that had travel restriction policies and experienced importation of COVID-19 are shown in supplemental tables 1 and 2. A total of 28 countries with imported COVID-19 cases have been identified. Twenty-one countries imported COVID-19 before the travel restriction (i.e., corresponds to (A)) and the other 7 countries imported COVID-19 after the travel restriction (i.e., corresponds to (B)). The arrival time ranged from 39 to 80 days since the first case was identified in Wuhan, China om 8 December, 2019.

Figures 3-5 plot the estimated risk reduction due to the travel restrictions and the associated change of effective distance for each airport. Figure 3 (Observed vs H1) shows the estimated relative risk reduction under the assumption of (H1). The median (Inter Quantile Range, IQR) of estimated absolute and relative risk reduction (i.e., $R_{ij}^{O} - R_{ij}^{H_1}$ and $1 - R_{ij}^{H_1}/R_{ij}^{O}$) were 0.000 (0.00, 0.000) and 0.000 (-0.115, 0.049), respectively. When reducing the global passenger volume from 25% to 0% between China and other airports, positive risk reduction was observed on the coastal area of the South American continent as well as the coastal area of the African continent, all of Europe and South East Asia. Figure 4 (Observed vs H2) shows the estimated relative risk reduction under the assumption of (H2). The median (IQR) of the estimated absolute and relative risk reduction (i.e., $R_{ij}^{O} - R_{ij}^{H_2}$ and $1 - R_{ij}^{H_2}/R_{ij}^{O}$) were -0.000 (-0.045, 0.000) and -1.000 (-0.740, 0.000) for 25% flight cancelation and 0.000 (-0.039, 0.000) and 0.000 (-0.300, 1.000) for 50% flight cancelation, respectively. Note that geographical distribution of the risk reduction in Figure 4 shows a similar tendency to Figure 3, except that there is a positive risk reduction effect in New Zealand and central Europe: when increasing the reduction in global passenger volume from 25% to 50% or 75% between China and other airports, positive risk reduction was observed in the areas shown in Figure 3. Figure 5 (Observed vs H3) shows the estimated relative risk reduction under the assumption of (H3). The median (IQR) of estimated absolute and relative risk reduction (i.e., $R_{ij}^{O} - R_{ij}^{H_3}$ and $1 - R_{ij}^{H_3}/R_{ij}^{O}$) were 0.000 (-0.394, 0.002) and 0.000 (-3.000, 1.000), respectively. This also shows a similar geographical tendency with Figure 3: almost all airports, especially in coastal areas of South America, coastal areas of A the African continent, the whole of Europe and South East Asia, have a chance to reduce the risk of importation of COVID-19 by closing the top 10 hub airports.

Discussion

This study estimated the absolute and relative reduction of risk of international dissemination of COVID-19 due to travel restrictions applied during 8 December 2019 (time of first onset in Wuhan) and 26 February 2020, using a hazard-based model and the idea of effective distance. The degree of travel restriction was assumed to be a 75% reduction in the passenger volume (Figure 3). As a result, almost all airports showed a minor change in the relative risk, suggesting that the travel restriction has only a minor reduction in risk of importation. To check the sensitivity of the effect of passenger volume on the relative risk reduction, we changed the degree of reduction in passenger volume from 75% to 50% or 25%. We observed a volume-dependent increase in relative risk in several areas including North America, Russia, and a part of Europe. Notably, a few areas showed increased and decreased relative risk in 50% and 75%, respectively (Figure 4), suggesting that the degree of passenger volume has a nonlinear effect on the risk reduction and the optimal size of volume reduction may depend on the airport network and vary among airports. Building upon these results, it can be concluded that travel restrictions based on passenger reductions would make only a minor contribution to the prevention of virus importation among countries.

To validate the risk reduction effect of shutting down the hub airports, we estimated the relative risk reduction under an assumption that the top ten hub airports (picked up by the degree of nodes) are closed (Figure 5). We observed that almost all airports experienced a decreased relative risk of virus importation under this strategy. However, the United States, India, and Australia showed increased relative risk of virus importation. One possibility underlying this result is that closing the hub airports increases the number of passengers in other airports, suggesting that a strategy of closing the appropriate hub airports may play a major role in risk reduction in virus importation. Another possibility is that this closure slightly reduced absolute risk of importation, but adjusted the balance of relative risks by changing the relative importance of specific airports (i.e. redefining which airports were the top hub airports).

Air travel is not the only driving force of virus spread. The impact of sea and ground (such as car and railway) transportation on virus spread could be larger than that of aircraft in areas where countries are adjacent to each other, such as Europe. Therefore, an interesting next study may be to calculate the effective distance based on the transportation data from air, sea, and ground travel. In addition, as with previous studies [10, 20], the infected individual was assumed to be randomly selected from China. Therefore, if the infected individuals had some characteristics, such as a preference for a particular route from China to other destinations derived based on travel cost or visa restrictions, our results might be biased.

In summary, our study showed the impact of travel restrictions was limited for most airports with almost zero (median) relative risk reduction. However, we identified several sensitive airports to the restriction with a high relative risk reduction. Although, in such airports, the strategy to control the airline network on national borders may reduce the risk of importation of COVID-19, the travel ban will be a significant economic and social impact across countries [21]. Our study highlights the travel restrictions must be addressed based on a scientific-based risk assessment and the need for most countries to strengthen local capacities for disease monitoring and control, rather than controlling the importation of COVID-19 via airline networks.

Footnotes

Contributors:

SS and DY led the study. All authors took responsibility for the integrity of the data and the accuracy of the data analysis. All the authors made critical revisions to the manuscript for important intellectual content and gave final approval of the manuscript. The opinions, results, and conclusions reported in this paper are those of the authors and are independent from the funding bodies.

Competing interests:

None.

Funding:

None.

References

1. Control, E.C.f.D.P.a. *Geographical distribution of 2019-nCov cases globally*. 2020; Available from: https://www.ecdc.europa.eu/en/geographical-distribution-2019-ncov-cases.
2. World Health Organization, *Coronavirus disease 2019 (COVID-19) Situation Report* 2020.
3. Linton, N.M., et al., *Epidemiological characteristics of novel coronavirus infection: A statistical analysis of publicly available case data.* medRxiv, 2020: p. 2020.01.26.20018754.
4. Chinazzi, M., et al., *The effect of travel restrictions on the spread of the 2019 novel coronavirus (COVID-19) outbreak.* Science, 2020.
5. World Health Organization, *Statement on the second meeting of the International Health Regulations (2005) Emergency Committee regarding the outbreak of novel coronavirus (2019-nCoV)*. 2020; Available from: https://www.who.int/news-room/detail/30-01-2020-statement-on-the-second-meeting-of-the-international-health-regulations-(2005)-emergency-committee-regarding-the-outbreak-of-novel-coronavirus-(2019-ncov).
6. Khan, K., et al., *Spread of a novel influenza A (H1N1) virus via global airline transportation.* N Engl J Med, 2009. **361**(2): p. 212-4.
7. Colizza, V., et al., *The role of the airline transportation network in the prediction and predictability of global epidemics.* Proc Natl Acad Sci U S A, 2006. **103**(7): p. 2015-20.
8. Huang, Z., et al., *An open-access modeled passenger flow matrix for the global air network in 2010.* PLoS One, 2013. **8**(5): p. e64317.
9. Poletto, C., et al., *Assessing the impact of travel restrictions on international spread of the 2014 West African Ebola epidemic.* Euro Surveill, 2014. **19**(42).
10. Otsuki, S. and H. Nishiura, *Reduced Risk of Importing Ebola Virus Disease because of Travel Restrictions in 2014: A Retrospective Epidemiological Modeling Study.* PLoS One, 2016. **11**(9): p. e0163418.
11. Colizza, V., et al., *Predictability and epidemic pathways in global outbreaks of infectious diseases: the SARS case study.* BMC Med, 2007. **5**: p. 34.
12. Tatem, A.J., D.J. Rogers, and S.I. Hay, *Global transport networks and infectious disease spread.* Adv Parasitol, 2006. **62**: p. 293-343.
13. World Health Organization, *Coronavirus disease (COVID-19) outbreak*. 2020; Available from: https://www.who.int/emergencies/diseases/novel-coronavirus-2019.
14. The Center for Systems Science and Engineering, *Coronavirus COVID-19 Global Cases (2020)*. 2020; Available from: http://www.arcgis.com/apps/opsdashboard/index.html#/bda7594740fd40299423467b48e9ecf6.
15. World Health Organization, *Updated WHO recommendations for international traffic in relation to COVID-19 outbreak*. 2020; Available from: https://www.who.int/news-room/articles-detail/updated-who-recommendations-for-international-traffic-in-relation-to-covid-19-outbreak/.
16. Think Global Health, *Travel Restrictions on China due to COVID-19*. 2020; Available from: https://www.thinkglobalhealth.org/article/travel-restrictions-china-due-covid-19.

17. Nah, K., et al., *Predicting the international spread of Middle East respiratory syndrome (MERS).* BMC Infect Dis, 2016. **16**: p. 356.
18. Brockmann, D. and D. Helbing, *The hidden geometry of complex, network-driven contagion phenomena.* Science, 2013. **342**(6164): p. 1337-42.
19. Nah, K., et al., *Estimating risks of importation and local transmission of Zika virus infection.* PeerJ, 2016. **4**: p. e1904.
20. Cowling, B.J. and H. Yu, *Ebola: worldwide dissemination risk and response priorities.* Lancet, 2015. **385**(9962): p. 7-9.
21. OECD Economics Department. *Coronavirus: The world economy at risk*. 2020; Available from: http://www.oecd.org/berlin/publikationen/Interim-Economic-Assessment-2-March-2020.pdf.

Figure 1: Entire flight network before travel restrictions (as of 1st December 2019): color indicates the passenger volume (pv)

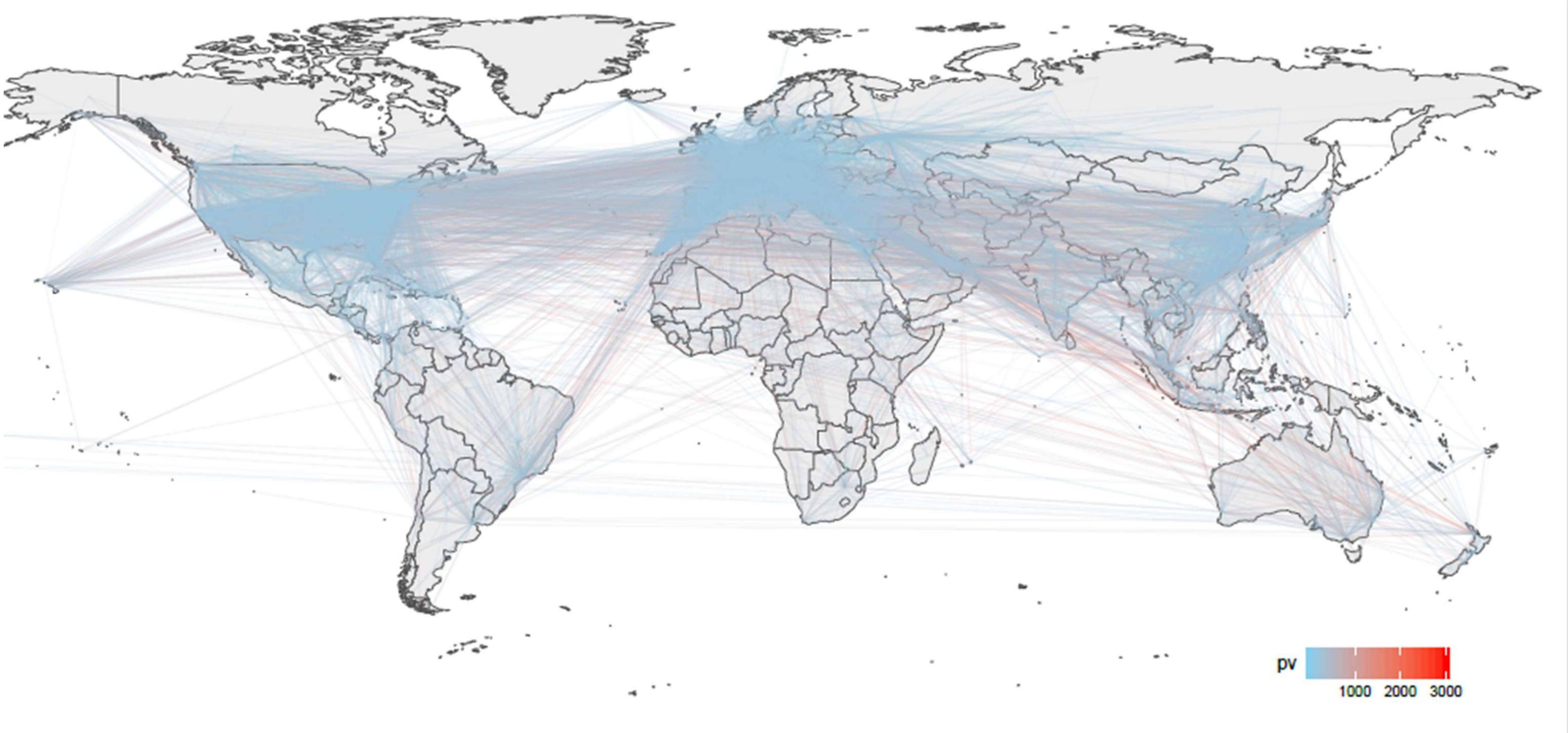


Figure 2: Flight network from China and Wuhan city before travel restrictions (as of 1st December 2019)

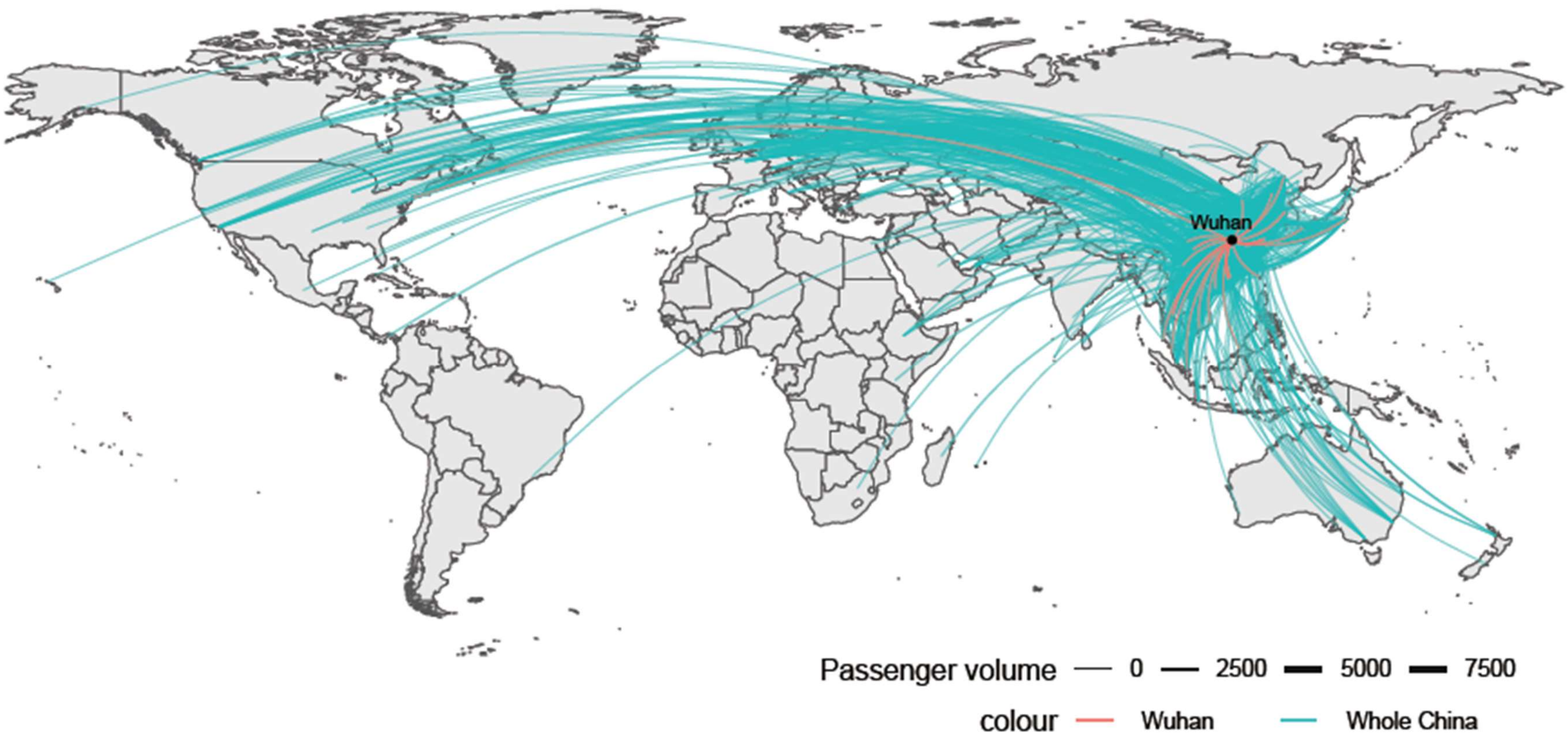


Figure 3: Estimated relative risk reduction under the assumption of H1: color indicates the estimated relative risk reduction and the size of circles indicates the number of inbound passenger volume of each airport

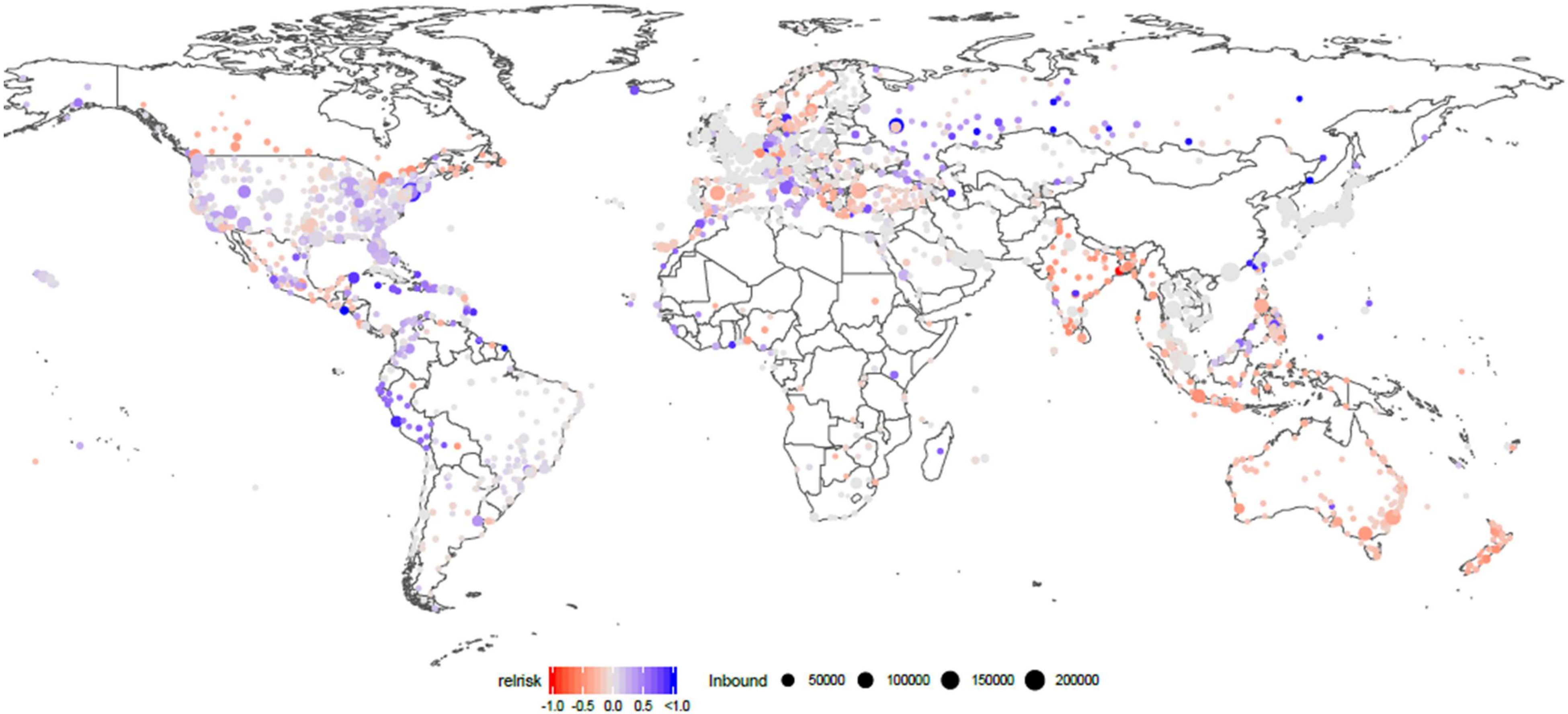


Figure 4: Estimated relative risk reduction under the assumption of H2 (a: 25% flight cancelation; b: 50% flight cancelation) : color indicates the estimated relative risk reduction and the size of circles indicates the number of inbound passenger volume of each airport

Figure 4a

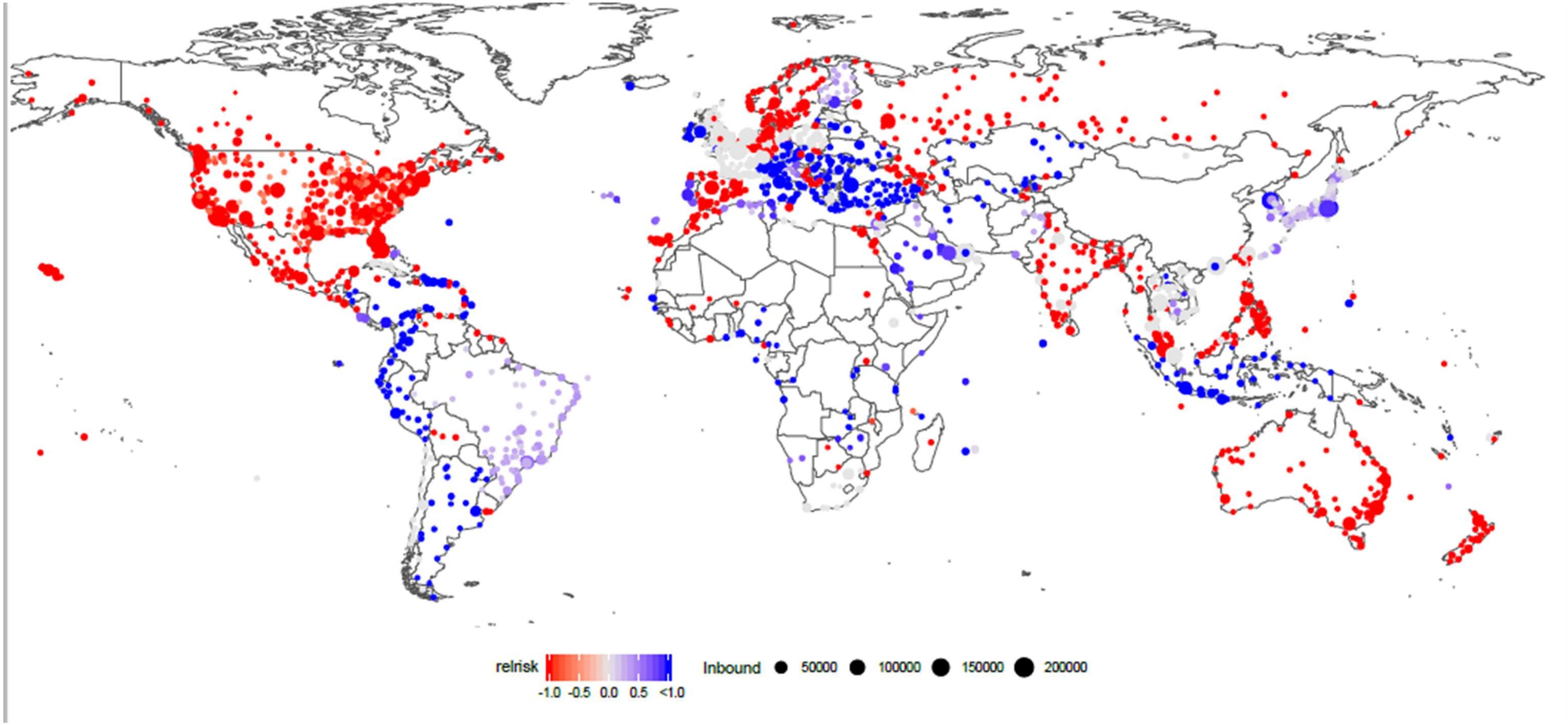


Figure 4b

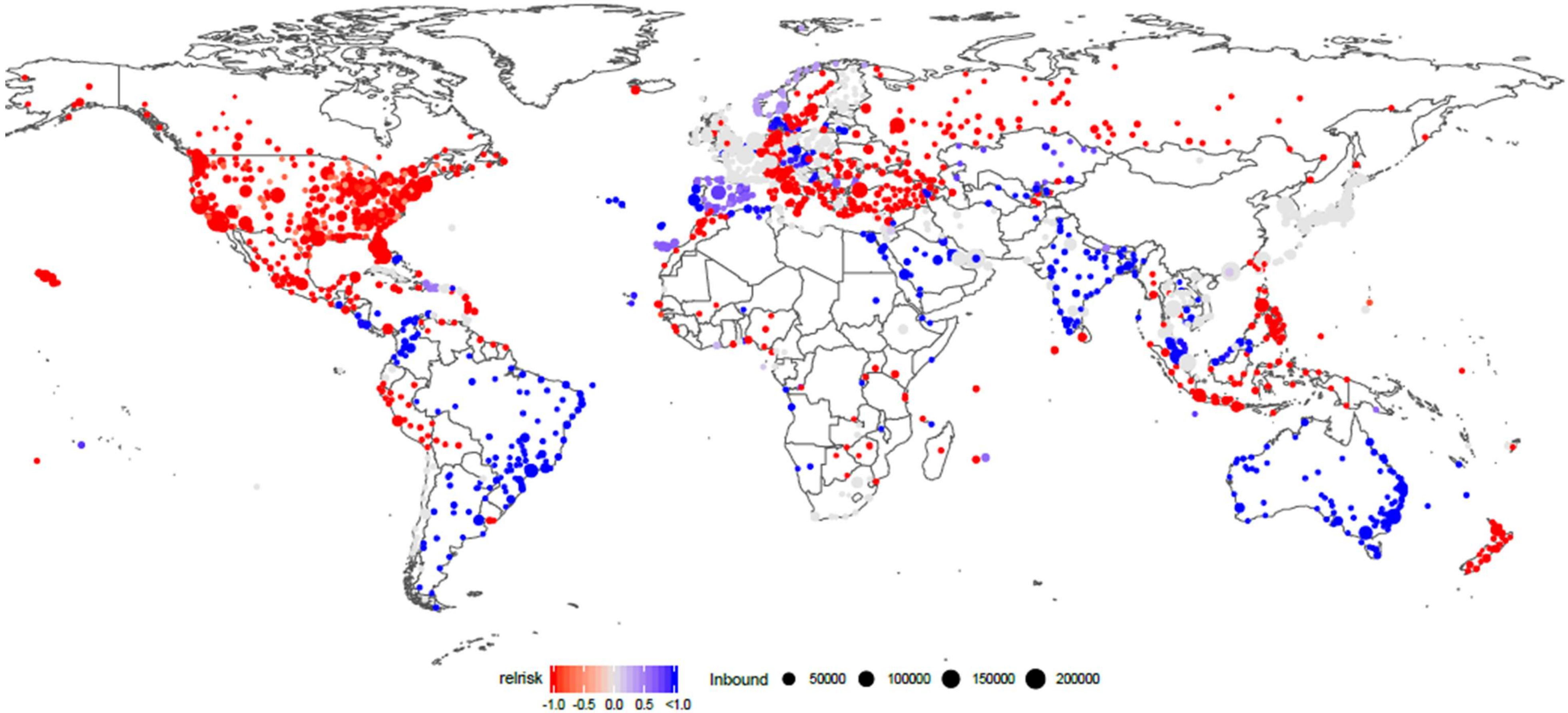
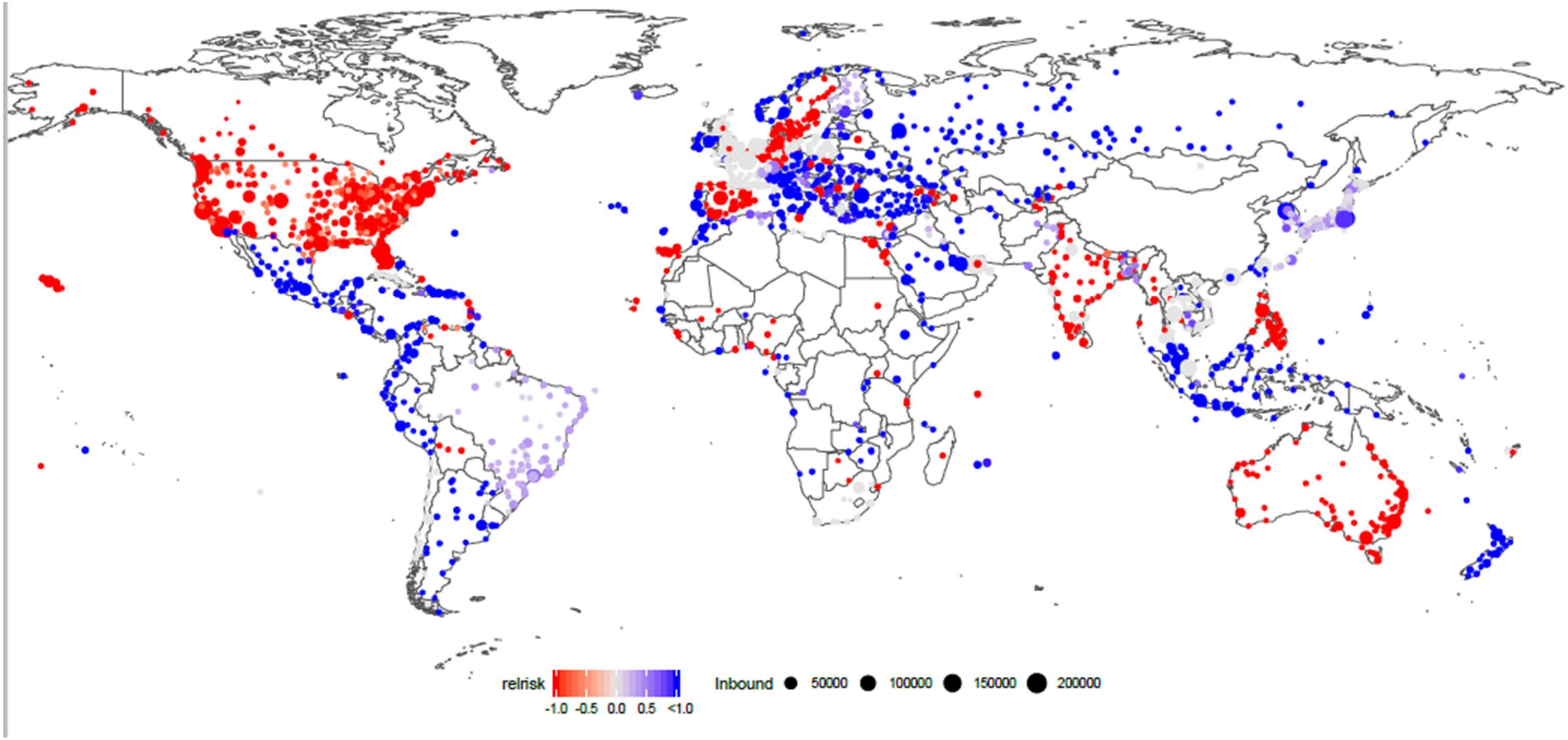


Figure 5: Estimated relative risk reduction under the assumption of H3: color indicates the estimated relative risk reduction and the size of circles indicates the number of inbound passenger volume of each airport



Supplementary table 1: List of countries that had travel restriction policies and their starting date

Country	Restriction start
Afghanistan	2020/01/30
Antigua and Barbuda	2020/01/31
Armenia	2020/02/01
Australia	2020/02/01
Austria	2020/02/14
Azerbaijan	2020/02/01
Bahamas	2020/01/30
Bahrain	2020/02/13
Bangladesh	2020/02/02
Belize	2020/02/08
Brunei	2020/01/31
Cook Islands	2020/01/31
Czech Republic	2020/02/09
Egypt	2020/02/01
El Salvador	2020/01/31
Fiji	2020/02/02
France	2020/01/30
French Polynesia	2020/02/07
Gabon	2020/02/07
Germany	2020/01/30
Grenada	2020/02/02
Guatemala	2020/01/31
Guyana	2020/01/31
Hong Kong	2020/01/27
India	2020/02/02
Indonesia	2020/02/02
Iran	2020/01/31
Iraq	2020/02/02
Israel	2020/02/02
Italy	2020/01/31
Jamaica	2020/01/31
Japan	2020/02/01
Jordan	2020/02/05
Kazakhstan	2020/02/03
Kenya	2020/01/31
Kuwait	2020/02/06
Kyrgyzstan	2020/02/01
Laos	2020/02/02
Macau	2020/01/28

Madagascar	2020/02/11
Malaysia	2020/02/09
Maldives	2020/02/03
Mauritius	2020/02/02
Mongolia	2020/02/06
Morocco	2020/01/31
Mozambique	2020/01/28
Nauru	2020/02/04
New Zealand	2020/02/02
Niue	2020/02/03
Oman	2020/02/03
Palau	2020/02/01
Papua new guinea	2020/01/29
Paraguay	2020/01/31
Philippines	2020/01/27
Qatar	2020/02/03
Russia	2020/01/31
Rwanda	2020/01/30
Saint Kitts and Nevis	2020/02/01
Saint Lucia	2020/02/04
Samoa	2020/02/04
Saudi Arabia	2020/02/02
Seychelles	2020/01/29
Singapore	2020/01/29
South Korea	2020/02/04
Sri Lanka	2020/01/28
Suriname	2020/02/05
Switzerland	2020/01/30
Taiwan	2020/02/07
Tajikistan	2020/01/30
Tanzania	2020/01/29
Tonga	2020/02/03
Trinidad and Tobago	2020/01/30
Turkey	2020/02/05
Turkmenistan	2020/01/31
United Arab Emirates	2020/02/05
United Kingdom	2020/02/14
United States	2020/02/02
Uzbekistan	2020/02/01
Vanuatu	2020/02/09
Vietnam	2020/02/01

Supplementary table 2: List of countries that experienced importation of COVID-19 and their first onset date

Country	First onset date
Japan	2020/01/16
Thailand	2020/01/16
Korea	2020/01/20
United States	2020/01/22
Singapore	2020/01/23
Nepal	2020/01/24
Australia	2020/01/25
Canada	2020/01/27
Pakistan	2020/01/27
Germany	2020/01/28
Sri Lanka	2020/01/28
Finland	2020/01/30
India	2020/01/30
Philippines	2020/01/30
Belgium	2020/02/06
Spain	2020/02/06
Cambodia	2020/02/06
Swden	2020/02/06
Egypt	2020/02/15
Lebanon	2020/02/22
Israel	2020/02/23
Iraq	2020/02/23
Afganistan	2020/02/24
Bahrain	2020/02/24
Switzerland	2020/02/25
Croatia	2020/02/25
Brazil	2020/02/26
Algeria	2020/02/26