The impact of air temperature and containment measures on mitigating the intra-household transmission of SARS-CoV-2 : a data-based modeling analysis

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Supplementary methods

The stochastic ScEIQR epidemiological model

To simulate the epidemiological data of COVID-19 intra-household transmission under NPIs implementation, we developed an early spreading, early non-pharmaceutical-intervention stochastic model, denoted as ScEIQR model. The flow diagram of ScEIQR model was as the following, which demonstrated as following:

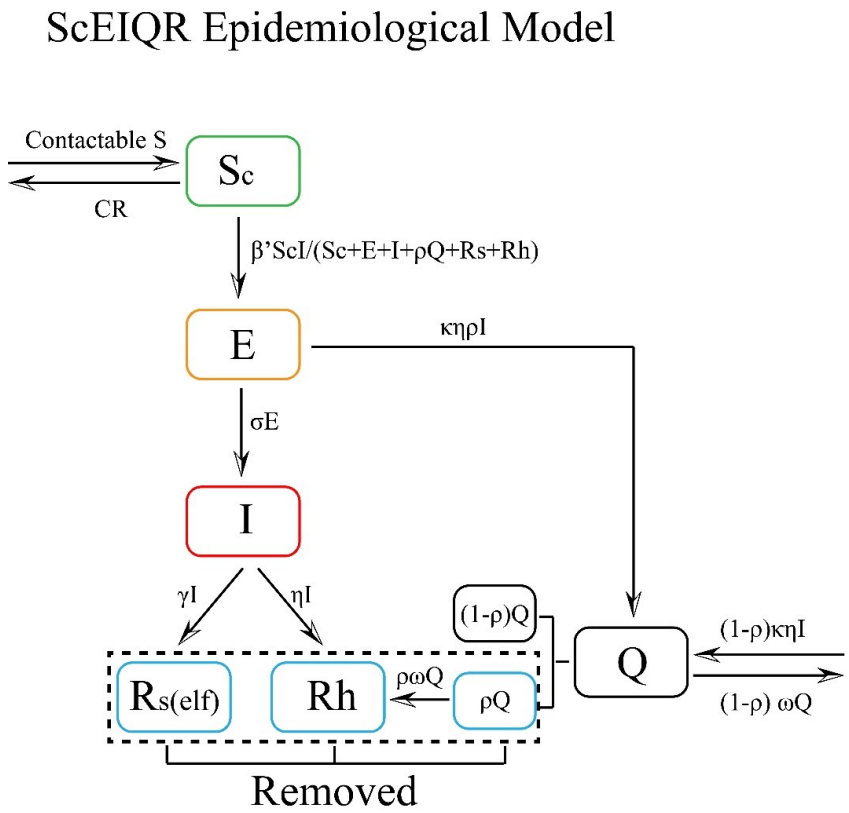

Figure 1

Compartments of the stochastic ScEIQR model

Sc: The contactable susceptible subpopulation for the infectors, comprised of their family, relatives, co-workers, friends, and some strangers who could be contacted by the infector under the interventive social prevention. The initial Sc is defined as a continuous random variable with Gaussian distribution in the model. The left arrow of Sc means the susceptible could be entered into this compartment to become the contactable susceptible (just a part of the susceptible) at the rate of c.

E: The exposed individuals who are in the incubation period after effective contact with the infectors.

I: The infectors, either immigrant or local reproductive infectors who are still outsides of the public health measures.

Q: The close contacts of infectors found out by epidemiological survey, and notified to be in self-quarantine at home, in the hotel or indicated isolating room for 14-day medical observation. The Q value in this model is the daily reported cumulative close contacts or entry of medical observation minus the daily cumulative dismission of medical observation for each province. The right arrow of Q means the quarantined individuals who are not be diagnosed as infectious leave the compartment Q to be the susceptible again at the rate of $(1-\rho)\,\omega Q$, the opposite arrow means the susceptible in close contacts (in fact, only a small part of close contacts in contact tracing were infected, and the other were still the susceptible) enter the compartment Q at the rate of $(1-\rho)\kappa\eta I$.

Rs(elf): No all the infectious may see a doctor, especially the non-symptoms infectors. Some of the COVID-19 cases can be self-healing. Thus, the self-recovery individuals who have never be diagnosed and hospitalized because of mild symptoms, or asymptomatic infection, and thus were not be recorded in the daily official epidemic reports is designated as Rs.

Rh: The cumulative individuals who were etiologically diagnosed (mostly SARS-CoV-2 RNA rtPCR positive in oropharyngeal swabs, and inconsistent with other clinical symptoms) and hospitalized in isolate wards. The cumulative number includes any hospitalizing, or dead, or cured COVID-19 patients. In China, every confirmed case had been hospitalized in isolation wards, he/she cannot infect others, so can be regarded as removed.

Removed: The removed means any infectors who have been deprived of the ability to propagate, either by the gain of immunity (Rs, cured in Rh) or by public health measures (infectors in Q, the hospitalizing in Rh), or death (the dead in Rh). The removed in this model is the sum of cumulative Rs, Rh, and the positive cases in Q. So, the flow velocity to Rs and Rh was different.

Model validation

The value of parameters was randomly sampled with one of MCMC method, Metropolis-Hastings (M-H) algorithm, and documented under an appropriate tolerance of best fitting with at least 100000 iterations of 0.1 step size from 0 to 60 days with burn-in of 50000 iterations for every province of Mainland China.

Other indexes

CR： restriction factor, the proportion of contactable susceptible (Sc) over the total population of a province under the interventive social prevention, which is simply calculated as Sc/N.

utI%: the proportion of the self-recovery removed, including asymptomatic infections or any infection without hospitalization and report, which were estimated as $\gamma/(\eta+\kappa\rho\eta+\gamma)$.

SurveyQ: an estimation for the quality of the epidemical survey, which is calculated as $\kappa \bullet \rho$.

Incubation period: The incubation period was the time elapsed from exposure to SARS-COV-2 to the symptoms firstly apparent, calculated with $1/\sigma+1/\eta$.

Communicable period: The time for untraceable infectors with contagious among susceptible, calculating with $1/\gamma$.

The air temperature of every province during the COVID-19 outbreak and spreading

The historical meteorological data were collected from china's meteorological administration. The daily mean air temperature was calculated from Jan 15, 2020 to Feb 15, 2020, i.e., from a week before Jan 23, 2020, to 3 weeks after that. In this period, COVID-19 began spreading and controlled by NPI in most of the provinces of China, except Hubei.

The epidemical data and epidemical survey of 31 provinces

The daily confirmed and quarantined cases were used for fitting the model. Almost all the diagnosed cases were hospitalized in isolation wards simultaneously according to the Guidance, thus the reported confirmed cases were just the hospitalized infectors in China. Cases confirmed with a laboratory test of the same sample identified two targets positive detection with real-time reverse-transcription-polymerase-chain-reaction (RT-PCR) assay or high-throughput sequencing, one is ORF, another one is the N protein of SARS-CoV-2. The quarantined cases were the population close contact the confirmed cases, asymptomatic infections, and suspected cases identified with epidemiological investigation within 24 hours. The close contacts were including:

1) living, studying, working in the same house with the confirmed or suspected cases.

2) medical staff, family members, or other persons who have close contact with cases in the process of diagnosis, treatment, or nursing.

3) take the same transport and have close contact with infectors, including caregivers, peers, or other passengers(*31*).

The quarantined people were isolated in the home or a specific place for observation of their symptoms for 14 days. If the lab testing results of close contacts of confirmed cases and asymptomatic infections are negative during the medical observation period, they still need to continue quarantine until the end of the observation of 14 days. Those who are in close contact with suspected cases can be relieved of medical observation when suspected cases are excluded from infection.

The provinces of China

There are 34 provincial-level administrative divisions of China, including 23 provinces, 4 municipalities (Beijing, Tianjin, Shanghai, Chongqing), 5 autonomous regions (Guangxi, Inner Mongolia, Tibet, Ningxia, Xinjiang) and 2 special administrative regions (Hong Kong, Macau). 23 provinces are including Anhui, Fujian, Gansu, Guangdong, Guizhou, Hainan, Hebei, Heilongjiang, Henan, Hubei, Hunan, Jiangsu, Jiangxi, Jilin, Liaoning, Qinghai, Shaanxi, Shandong, Shanxi, Sichuan, Yunnan, Zhejiang, Taiwan. Seven geographical regions were classified as Mainland China, named as North China, Northeast China, East China, Central China, South China, Northwest China, Southwest China. The 29 provinces were included in our study, and they were separated into each geographical region and represented by numbers as follows:

1) North China: Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia (1-5);

2) Northeast China: Liaoning, Jilin, Heilongjiang (6-8);

3) East China: Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Shandong (9-15) and Taiwan;

4) Central China: Henan, Hubei, and Hunan (16-18);

5) South China: Guangdong, Hainan, Guangxi (19-21), Hongkong, and Macau;

6) Northwest China: Shaanxi, Gansu, Ningxia, Xinjiang (22-25) and Qinghai;

7) Southwest China: Chongqing, Sichuan, Guizhou, Yunnan (26-29), and Tibet.

Supplementary tables

Table S1. The mean value of parameters and indexes in each province of mainland China

	Parameters and indexes (Mean±SD)										
Province	**β'**	**σ**	**γ**	**η**	**κ**	**ρ(%)**	**ω**	**CR**	**Ipd (day)**	**utl%**	**Survey Q**
All provinces	10.01±2.86	0.42±0.04	0.16±0.07	0.68±0.20	45.55±28.66	1.32±1.30	0.12±0.03	1.58E-05±7.88E-05	4.31±1.18	15.63±9.27	0.46±0.53
Beijing	11.63±2.48	0.35±0.02	0.23±0.05	0.69±0.04	5.59±0.17	0.78±0.12	0.07±0	1.24E-06±3.24E-07	4.34±0.19	24.22±3.57	0.04±0.01
Tianjin	9.58±2.89	0.33±0.03	0.08±0.03	0.83±0.06	12.79±0.72	0.49±0.12	0.07±0	6.35E-07±1.95E-07	3.71±0.3	8.7±2.58	0.06±0.02
Hebei	9.22±3.44	0.41±0.06	0.22±0.06	0.47±0.18	46.56±6.34	0.47±0.24	0.16±0.02	3.38E-07±1.27E-07	5.05±1.07	30.75±13.89	0.22±0.11
Shanxi	9.29±4.2	0.41±0.05	0.14±0.07	0.41±0.18	65.78±15.26	2.49±0.57	0.14±0.02	3.77E-07±1.82E-07	3.89±1.29	13.35±7.9	1.68±0.64
Neimenggu	8.77±3.12	0.44±0.03	0.22±0.04	0.47±0.11	62.99±5.38	0.27±0.08	0.15±0.01	2.34E-07±9.11E-08	4.55±0.59	29.11±6.61	0.17±0.06
Liaoning	9.81±3.38	0.48±0.02	0.13±0.04	0.43±0.06	27.96±1.68	1.82±0.27	0.12±0.01	1.64E-07±5.09E-08	4.46±0.35	15.98±4.01	0.51±0.08
Jilin	9.85±4.85	0.41±0.06	0.15±0.06	0.89±0.07	58.58±14.51	1.35±0.28	0.13±0.03	6.15E-07±3.60E-07	3.6±0.38	8.62±3.27	0.77±0.2
Heilongjiang	7.39±1.62	0.44±0.03	0.07±0.01	0.93±0.05	27.83±1.98	0.98±0.16	0.11±0.01	1.53E-06±3.76E-07	3.35±0.19	5.43±0.73	0.27±0.05

Shanghai	10.53±1.01	0.41±0.07	0.12±0.01	0.9±0.05	64.41±2.25	1.6±0.19	0.21±0.02	1.84E-06±1.44E-07	5.44±0.54	6.22±0.42	1.03±0.15
Jiangsu	11.06±3.55	0.44±0.04	0.1±0.03	0.88±0.05	32.43±3.1	1.08±0.12	0.15±0.01	6.53E-07±1.96E-07	3.45±0.24	8.01±2.27	0.35±0.06
Zhejiang	15.06±2.46	0.48±0.02	0.11±0.03	0.64±0.08	34.64±2.55	1.33±0.16	0.1±0.01	1.00E-06±2.37E-07	3.67±0.24	10.83±2.35	0.46±0.06
Anhui	12.31±3.55	0.38±0.03	0.14±0.07	0.57±0.15	36.65±4.4	1.61±0.29	0.13±0.01	9.51E-07±2.86E-07	4.55±0.55	13.88±7.03	0.59±0.11
Fujian	12.66±3.09	0.45±0.03	0.23±0.04	0.46±0.12	42.01±2.93	0.31±0.14	0.13±0.01	3.89E-07±1.17E-07	4.55±0.61	32.08±7.71	0.13±0.06
Jiangxi	12.38±2.91	0.41±0.03	0.05±0.01	0.75±0.08	48.15±2.52	0.86±0.11	0.16±0.01	1.13E-06±2.36E-07	3.81±0.18	4.59±0.8	0.41±0.07
Shandong	13.3±2.94	0.35±0.06	0.1±0.06	0.16±0.03	51.26±3.2	5.09±0.69	0.08±0.01	2.36E-07±9.04E-08	9.62±1.3	14.88±5.82	2.61±0.42
Henan	13.4±2.8	0.45±0.03	0.26±0.03	0.62±0.16	24.87±2.71	0.31±0.18	0.12±0.01	6.84E-07±1.90E-07	4.56±0.95	34.36±8.6	0.08±0.05
Hubei	3.29±0.34	0.42±0.05	0.23±0.04	0.95±0.03	5.35±0.62	4.28±0.48	0.11±0.01	4.33E-04±8.35E-05	3.48±0.29	16.49±2.9	0.23±0.03
Hunan	10.22±2.73	0.45±0.03	0.07±0.01	0.86±0.05	38.98±2.47	1.22±0.2	0.16±0.01	1.35E-06±3.82E-07	3.42±0.19	5.44±1.2	0.48±0.09
Guangdong	7.14±1.79	0.44±0.04	0.16±0.06	0.78±0.06	14.33±1.33	4.87±1.82	0.17±0.02	2.01E-06±6.07E-07	3.58±0.26	11.14±3.78	0.69±0.25
Hainan	4.39±1.63	0.44±0.04	0.07±0.03	0.68±0.07	23.03±1.83	1±0.18	0.08±0.01	3.32E-06±1.31E-06	3.78±0.25	8.17±3.17	0.23±0.05
Guangxi	10.95±2.94	0.46±0.02	0.05±0	0.9±0.03	52.88±2.53	0.82±0.08	0.11±0	4.45E-07±1.51E-07	3.27±0.13	3.92±0.3	0.43±0.05
Shaanxi	7.44±3.41	0.4±0.05	0.22±0.05	0.44±0.18	76.13±8.4	0.33±0.17	0.1±0.01	7.43E-07±4.38E-07	5.52±1.91	31.44±13.72	0.25±0.13
Gansu	12.46±3.04	0.45±0.03	0.2±0.05	0.76±0.09	41.99±3.6	0.92±0.14	0.1±0.01	2.66E-07±7.72E-08	3.56±0.27	16.08±4.02	0.39±0.07
Ningxia	7.24±4.41	0.36±0.06	0.17±0.07	0.56±0.17	70.9±11.44	0.37±0.26	0.11±0.02	1.53E-06±1.10E-06	4.91±1.29	21.31±12.15	0.27±0.19
Xinjiang	5.21±2.13	0.41±0.05	0.23±0.05	0.82±0.1	147.79±11.06	0.03±0.01	0.08±0	7.34E-07±3.67E-07	3.71±0.32	21.32±5.08	0.05±0.02
Chongqing	8.47±3.31	0.42±0.03	0.22±0.04	0.57±0.08	39.36±6.01	0.22±0.16	0.13±0.01	1.66E-06±5.67E-07	4.17±0.34	26.52±5.82	0.09±0.08
Sichuan	10.9±1.96	0.38±0.03	0.21±0.04	0.79±0.03	46.84±3.25	0.99±0.07	0.12±0.01	5.92E-07±9.07E-08	3.89±0.22	15.47±2.48	0.47±0.05
Guizhou	14.87±2.03	0.35±0.03	0.09±0.02	0.97±0.02	23.7±3.5	1.86±0.37	0.17±0.02	2.63E-07±3.44E-08	3.92±0.25	6.25±1.45	0.45±0.13
Yunnan	11.49±3.82	0.44±0.04	0.25±0.04	0.44±0.18	97.33±33.65	0.59±0.19	0.15±0.04	2.60E-07±1.18E-07	5.14±1.62	28.89±8.82	0.59±0.31

Abbreviation: Ipd: Incubation period; utI%: Proportion of Untraceable infectors;

Supplementary figure legend

Figure S1. The fitting curves of both the number of daily cumulative confirmed cases and close contacts being in quarantine in 22 provinces of Mainland China (Day 0, the 23rd, Jan, 2020).

A: The fitting curve of provinces in Northwest China- Xinjiang/ Shaanxi/ Ningxia and Central China-Hunan/ Henan.

B: The fitting curve of provinces in South China- Hainan/ Guangxi, and Southwest China-Yunnan/ Guizhou/ Chongqing.

C: The fitting curve of provinces in East China- Shanghai/ Zhejiang/ Anhui/ Fujian/ Shandong/ Jiangsu.

D: The fitting curve of provinces in North China- Neimenggu/ Tianjin/ Hebei/ Shanxi and Northeast China- Heilongjiang/ Jilin.

Figure S2. Suppositional simulation of contact tracing parameters, κ and ρ.

A-B: The median κ and ρ was calculated among 29 provinces.

C-D: The influence on Rh, Q and I compartment after adjustment of κ by 30% or 50%.

E-F: The simulated Rh, Q and I compartment after adjustment of ρ by 30% or 50%.

Figure S3. The median incubation period of COVID-19 among 29 provinces.