Supplementary Materials for

Impact of Temperature and Relative Humidity on the Transmission of COVID-19: A Modeling Study in China and the U.S.

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Materials and Methods

Fama-MacBeth Regression with Newey-West Adjustment

Fama-MacBeth regression is a way to study the relationship between the response variable and the features in the panel data setup. Particularly, Fama-MacBeth regression runs a series of cross-sectional regressions and uses the average of the cross-sectional regression coefficients as the second step of parameter estimation. In equation form, for n response variables, m features and time series length T

$$\begin{gathered}R_{i,1} = \alpha_1 + \beta_{1,1}F_{1,i,1} + \beta_{2,1}F_{2,i,1} + \cdots + \beta_{m,1}F_{m,i,1} + \epsilon_{i,1},\\ R_{i,2} = \alpha_2 + \beta_{1,2}F_{1,i,2} + \beta_{2,2}F_{2,i,2} + \cdots + \beta_{m,2}F_{m,i,2} + \epsilon_{i,2},\\ \cdots \\ R_{i,T} = \alpha_T + \beta_{1,T}F_{1,i,T} + \beta_{2,T}F_{2,i,T} + \cdots + \beta_{m,T}F_{m,i,T} + \epsilon_{i,T}.\end{gathered}$$

where $R_{i,t}, i \in \{1, \ldots, \mathrm{n}\}$ are the response values, $\beta_{k,t}$ are first step regression coefficients for feature k at time t, and $F_{k,i,t}$ are the input features of feature k and sample i at time t. In the second step, the average of the first step regression coefficient, $\hat{\beta}_k$, can be calculated directly, or via the following regression

$$\beta_{k,t} = c_k + \epsilon_t.$$

where ϵ_t is the random noise.

Since βs might have time-series autocorrelation, in the second step, we thus use the Newey-West approach [1] to adjust the time-series autocorrelation (and heteroscedasticity) in calculating standard errors. Specifically, for the second step, we have

$E[\epsilon] = 0$ and $E[\epsilon\epsilon'] = \sigma^2\Omega$.

The covariance matrix of c_k is

$$V_{C_k} = \frac{1}{T}\left(\frac{1}{T}\mathbf{1}'\mathbf{1}\right)^{-1}\left(\frac{1}{T}\mathbf{1}'(\sigma^2\Omega)\mathbf{1}\right)\left(\frac{1}{T}\mathbf{1}'\mathbf{1}\right)^{-1},$$

where $\mathbf{1}$ is a $T \times 1$ vector of 1 and $\sigma^2\Omega$ is the covariance matrix of errors.

The middle matrix can be rewritten as

$$Q = \frac{1}{T}\mathbf{1}'(\sigma^2\Omega)\mathbf{1}$$
$$= \frac{1}{T}\sum_{i=1}^{T}\sum_{j=1}^{T}\sigma_{ij}$$

The Newey-West estimators give a consistent estimation of Q when the residuals are autocorrelated and/or heteroscedastic. The Newey-West estimator can be expressed as

$$S = \frac{1}{T}\left(\sum_{t=1}^{T} e_t^2 + \sum_{l=1}^{L}\sum_{t=l+1}^{T} w_l e_t e_{t-l}\right),$$

where $w_l = 1 - \frac{l}{1+L}$, e represents residuals and L is the lag.

We use Fama-Macbeth regressions for two reasons. First, the temperature and relative humidity series have trends with the arrival of summer and the R value series also has downward trends. In this case, panel regression will obtain spurious regression results from the time-series perspective. However, the cross-sectional regression involving cities (counties) of various meteorological conditions and COVID-19 spread intensities will not have spurious regression issues. Second, Fama-MacBeth regression is valid even in the presence of cross-sectional heteroskedasticity (including complex spatial covariance) because in the second-step regression, only the value of the first step estimates βs are used, not their standard errors. Therefore, as long as the first-step estimator is unbiased, which is the case for heteroskedasticity (including complex spatial covariance), the Fama-MacBeth estimation is correct.

Less rigorously speaking, we use the first step of Fama-MacBeth regression to determine the extent to which the transmissibility of the areas of high temperature and high relative humidity are compared with that of low temperature and low relative humidity areas each day. We then use the second step to test whether daily relationships are a common fact during a given time period.

Estimating the Effective Reproduction Number

The basic reproduction number R_0, which characterizes the transmission ability of an epidemic, is defined as the average number of people who will contract the contagious disease from a typical infected case in a population where everyone is susceptible. When an epidemic spreads through a population, the time-varying effective reproduction number R_t is of greater concern. The effective reproduction number R_t, the R value at time step t, is defined as the actual average number of secondary cases per primary case cause[2].

We then calculate the effective reproductive number R_t for each city through a time-dependent method based on maximun likelihood estimation (MLE)[3]. The inputs to the method are epidemic curves, *i.e.*, the historical numbers of patients in each day, for a certain city. Specifically, we denote $w(\tau|\theta)$ as the probability distribution for the serial interval, which is defined as the time between symptom onset of a case and symptom onset of her/his secondary cases. Let $p_{(i,j)}$ be the relative likelihood that case i has been infected by case j, given the difference in time of symptom onset $t_i - t_j$, which can be expressed in terms of $w(\tau|\theta)$. That is, the relative likelihood that case i has been infected by case j can be expressed as

$$p_{ij} = \frac{w(t_i - t_j)}{\sum_{i \neq k} w(t_i - t_k)}$$

The relative likelihood of case i infecting case j is independent of the relative likelihood of case i infecting any other case k. The distribution of the effective reproduction number for case i is

$$R_i \sim \sum_j \text{Bernoulli}[p_{(j,i)}]$$

With the expected value

$$E(R_i) = \sum_j p_{(j,i)}$$

The average daily effective reproduction number R_t is estimated as the average over R_i for all cases i who develop the first symptom of onset on day t.

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The above calculation is implemented with the package 'R0' developed by Boelle & Obadia with R version 3.6.2 and 'R0' version 1.2_6 (https://cran.r-project.org/web/packages/R0/index.html).

Modeling Spatial Effect

We use a generalized linear mixed model (GLMM) with spatial random effects to account for spatial autocorrelation between cities or counties in each cross-sectional regression. The form of the model is

$$\boldsymbol{y} = \boldsymbol{X\beta} + \boldsymbol{u} + \boldsymbol{\epsilon},$$

where $\boldsymbol{y}$ is the $N \times 1$ outcome vector, $\boldsymbol{X}$ is the $N \times p$ matrix of the p explanatory variables (the intercept term can be included by setting the first column of X as a vector of ones), $\boldsymbol{\beta}$ is the vector of regression coefficients, $\boldsymbol{u}$ is the vector of spatial random effects, and $\boldsymbol{\epsilon}$ is the random error vector whose entries are independent and identically distributed as $N(0, \sigma^2)$. We assume $\boldsymbol{u} \sim N(0, \boldsymbol{\sigma_s^2 G})$, *where* $\boldsymbol{\sigma_s^2}$ is the spatial variance and $\boldsymbol{G}$ follows a Matérn correlation structure[4].

The Matérn model flexibly specifies the correlation between any two cities or counties as a function of their geographical distance; the model has two parameters, a scale parameter ρ and a "smoothness" parameter ν, and it subsumes the exponential and squared exponential models as special cases. The maximum likelihood method is used for parameter estimation[5].

We have also tried a conditional autoregressive model (CAR)[6] in which the spatial correlation is described by an adjacency matrix of the cities/counties. The Matérn model performs better than the CAR model as judged by the Akaike information criterion (AIC); the average AIC value across all cross-sectional regressions is 896.9 and 936.5 for the Matérn model and the CAR model, respectively.

All computations are performed in the R package "spaMM" version 3.3.0[7]. We report the results from the Matérn model in Table S9 and S10.

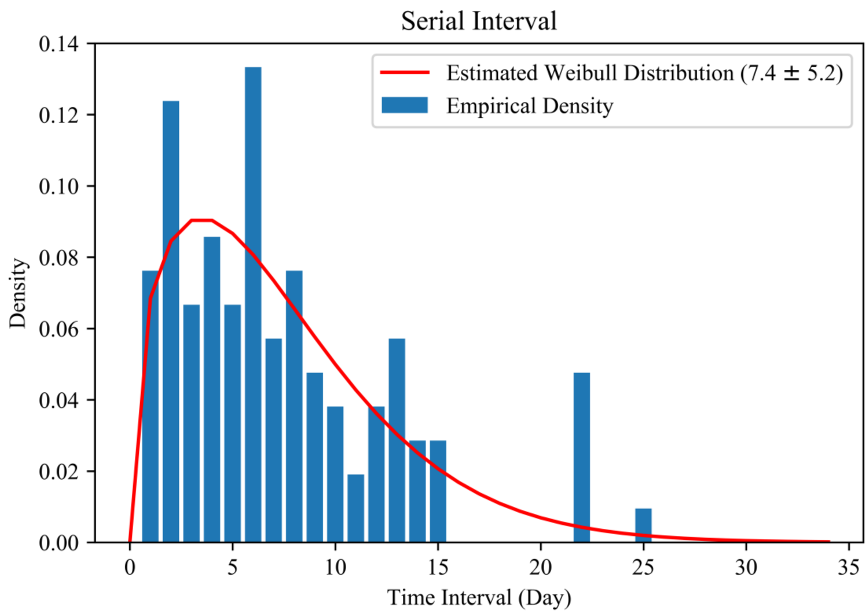

Fig. S1. Estimation of the serial interval with the Weibull distribution

Bars denote the probability of occurrences in specified bins, and the red curve is the density function of the estimated Weibull distribution.

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Table S1. Data Summary

This table summarizes the variables used in this paper. Panel A and B summarize the data of Chinese cities and the U.S. counties.

Panel A: Data Summary for the Chinese Cities

	Mean	Std	Min	Max
R	1.072	0.707	0.131	4.609
6-Day Average Temperature (Celsius)	4.468	6.842	-21.100	19.733
6-Day Average Relative Humidity (%)	77.147	9.589	48.667	99.833
GDP per Capita (RMB 10k)	6.800	3·716	2.159	18.957
Population Density (k/km^2)	0.692	0.812	0.00800	6.522
No· Doctors (k)	16.020	11.488	1.972	68.549
Proxy for Inflow population from Wuhan (10 k)	5.096	14.833	0.000	138.154
Fraction over 65	0.121	0.0186	0.0826	0.152
Drop of BMI compared to first week 2020	-0.413	0.347	-0.886	0.759

Panel B: Data Summary for the U.S. Counties

	Mean	Std	Min	Max
R	1.517	0.836	0.040	4.997
6-Day Average Temperature (Celsius)	10.738	6.503	-10.192	28.826
6-Day Average Relative Humidity (%)	67.815	11.932	16.388	99.096
Population Density (/mile^2)	374.275	1678.13	2.562	48229.375
Fraction over 65	0.167	0.0423	0.0633	0.374
Gini index	0.449	0.0309	0.357	0.597
GDP per capita (k Dollar)	45.599	24.417	13.006	378.762
Fraction below poverty level	15.970	5.604	4.000	38.100
Personal income (Dollar)	46923.2	14586.7	26407	251728
Fraction of not in labor force, 16 years or over	38.842	6.737	19.600	62.000
Fraction of total household more than $200,000	3.564	2.948	0.400	23.100
Fraction of food stamp/SNAP benefits	13.854	5.355	1.400	38.800
No. ICU beds per 10000 capita	2.182	1.945	0.000	17.357
Fraction of maximum moving distance over normal time	33.286	25.918	0.000	478.000
Home-stay minutes	749.064	145.883	206.585	1275.341

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Table S2: Pairwise Correlation Analysis for Chinese Cities

Pairwise correlation coefficients are obtained by averaging all correlation coefficients from each time step in the Fama-Macbeth approach.

	Temperature	Relative Humidity	Population Density	Percentage over 65	GDP per capita	No. of doctors	Drop of BMI	Inflow population from Wuhan	Latitude	Longitude
Temperature	1.00	0.32	0.33	-0.37	0.33	0.13	-0.21	0.04	-0.92	-0.57
Relative Humidity	0.32	1.00	-0.08	0.01	-0.16	-0.09	0.29	0.09	-0.44	-0.32
Population Density	0.33	-0.08	1.00	-0.27	0.57	0.29	-0.40	-0.09	-0.27	-0.03
Percentage over 65	-0.37	0.01	-0.27	1.00	-0.20	0.13	0.25	0.06	0.45	0.13
GDP per capita	0.33	-0.16	0.57	-0.20	1.00	0.45	-0.76	-0.14	-0.25	0.05
No. of doctors	0.13	-0.09	0.29	0.13	0.45	1.00	-0.39	-0.12	-0.06	-0.22
Drop of BMI	-0.21	0.29	-0.40	0.25	-0.76	-0.39	1.00	0.04	0.12	-0.14
Inflow population from Wuhan	0.04	0.09	-0.09	0.06	-0.14	-0.12	0.04	1.00	-0.05	-0.12
Latitude	-0.92	-0.44	-0.27	0.45	-0.25	-0.06	0.12	-0.05	1.00	0.59
Longitude	-0.57	-0.32	-0.03	0.13	0.05	-0.22	-0.14	-0.12	0.59	1.00

Table S3: Pairwise Correlation Analysis for the U.S. Counties

Pairwise correlation coefficients are obtained by averaging all correlation coefficients from each time step in the Fama-Macbeth approach.

	Temperature	Relative Humidity	Population Density	Percentage over 65	Gini	Se-factor	No. of ICU beds per capita	M50_index	Home stay minutes	Latitude	Longitude
Temperature	1.00	0.17	0.01	-0.05	0.34	0.36	0.11	0.34	0.00	-0.90	0.04
Relative Humidity	0.17	1.00	-0.06	0.08	0.05	0.02	0.00	0.07	0.10	-0.20	0.12
Population Density	0.01	-0.06	1.00	-0.11	0.23	0.07	0.07	-0.19	0.11	0.01	0.10
Percentage over 65	-0.05	0.08	-0.11	1.00	0.02	0.14	-0.04	-0.03	-0.18	0.05	0.13
Gini	0.34	0.05	0.23	0.02	1.00	0.53	0.37	0.15	-0.17	-0.35	0.07
Socio-economic factor	0.36	0.02	0.07	0.14	0.53	1.00	0.21	0.32	-0.41	-0.34	0.00
No. of ICU beds per capita	0.11	0.00	0.07	-0.04	0.37	0.21	1.00	0.18	-0.10	-0.11	0.10
M50_index	0.34	0.07	-0.19	-0.03	0.15	0.32	0.18	1.00	-0.37	-0.37	-0.08
Home-stay minutes	0.00	0.10	0.11	-0.18	-0.17	-0.41	-0.10	-0.37	1.00	0.06	-0.08
Latitude	-0.90	-0.20	0.01	0.05	-0.35	-0.34	-0.11	-0.37	0.06	1.00	-0.06
Longitude	0.04	0.12	0.10	0.13	0.07	0.00	0.10	-0.08	-0.08	-0.06	1.00

Table S4: Unit Root Test for R, Temperature and Relative Humidity

Panel A and B show the results of Handri LM test [8] with null hypotheses of non-unit-roots, for Chinese cities and the U.S. counties, respectively.

Panel A: Test Results for Chinese Cities

	***R* value**	**Temperature**	**Relative Humidity**
z-stat	18.7472	51.1532	42.6092
p-value	0.0000	0.0000	0.0000

Panel B: Test Results for the U.S. Counties

	***R* value**	**Temperature**	**Relative Humidity**
z-stat	43.0116	61.0510	76.8665
p-value	0.0000	0.0000	0.0000

Table S5: Coefficients of temperature and relative humidity in first step of Fama-Macbeth Regression

Panel A and B show regression coefficients of temperature and relative humidity in the first step of Fama-Macbeth regression, for Chinese cities and the U.S. counties, respectively.

Panel A: Regression Coefficients for Chinese Cities

Date	Coefficient of Temperature	Coefficient of Relative Humidity
Jan, 19	-0.0373	-0.0109
Jan, 20	-0.0064	0.0009
Jan, 21	-0.0127	-0.0093
Jan, 22	-0.0309	-0.0121
Jan, 23	-0.0427	-0.0066
Jan, 24	-0.0249	0.0010
Jan, 25	-0.0238	-0.0062
Jan, 26	-0.0506	-0.0174
Jan, 27	-0.0526	-0.0159
Jan, 28	-0.0196	-0.0063
Jan, 29	-0.0340	-0.0101
Jan, 30	-0.0305	-0.0096
Jan, 31	-0.0391	-0.0087
Feb, 1	-0.0388	-0.0102
Feb, 2	-0.0248	-0.0097
Feb, 3	-0.0108	-0.0022
Feb, 4	-0.0091	0.0020
Feb, 5	0.0039	0.0040
Feb, 6	-0.0061	-0.0037
Feb, 7	-0.0034	0.0006
Feb, 8	0.0103	-0.0030
Feb, 9	-0.0077	-0.0067
Feb, 10	-0.0150	0.0052

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Panel B: Regression Coefficients for U.S. Counties

Date	Coefficient of Temperature	Coefficient of Relative Humidity
Mar, 15	-0.0402	-0.0190
Mar, 16	-0.0309	-0.0192
Mar, 17	-0.0052	-0.0129
Mar, 18	-0.0192	-0.0146
Mar, 19	-0.0412	-0.0237
Mar, 20	0.0224	-0.0114
Mar, 21	-0.0112	-0.0158
Mar, 22	-0.0138	-0.0169
Mar, 23	-0.0021	-0.0195
Mar, 24	-0.0107	-0.0166
Mar, 25	-0.0184	-0.0073
Mar, 26	-0.0231	-0.0095
Mar, 27	-0.0241	-0.0010
Mar, 28	-0.0468	0.0013
Mar, 29	-0.0314	0.0007
Mar, 30	-0.0533	0.0076
Mar, 31	-0.0403	0.0071
Apr, 1	-0.0386	-0.0003
Apr, 2	-0.0234	-0.0017
Apr, 3	0.0029	-0.0024
Apr, 4	0.0037	-0.0031
Apr, 5	-0.0177	-0.0010
Apr, 6	-0.0057	-0.0040
Apr, 7	-0.0041	-0.0028
Apr, 8	-0.0116	-0.0029
Apr, 9	-0.0138	-0.0032
Apr, 10	-0.0123	-0.0032
Apr, 11	-0.0211	-0.0021

Date	Coefficient of Temperature	Coefficient of Relative Humidity
Apr, 12	-0.0297	-0.0002
Apr, 13	-0.0244	-0.0008
Apr, 14	-0.0310	-0.0016
Apr, 15	-0.0295	-0.0012
Apr, 16	-0.0271	-0.0010
Apr, 17	-0.0297	0.0022
Apr, 18	-0.0245	0.0027
Apr, 19	-0.0196	0.0020
Apr, 20	-0.0110	-0.0012
Apr, 21	0.0068	-0.0002
Apr, 22	0.0126	-0.0015
Apr, 23	0.0061	-0.0033
Apr, 24	0.0216	-0.0028
Apr, 25	0.0186	-0.0030

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Table S6: Fama-Macbeth Regression for Chinese Cities except Wuhan

Daily *R* values from January 19 to February 10 and the average temperature and relative humidity over 6 days up to and including the day when *R* value is measured, are used in the regression for 99 Chinese cities (without Wuhan). The regression is estimated by the Fama-MacBeth approach.

	Overall	**Before Lockdown (Jan 24)**	**After Lockdown (Jan 24)**
R2	0.3029	0.1915	0.3339
Temperature			
coef	-0.0223	-0.0287	-0.0205
95%CI	[-0.0358, -0.0088]	[-0.0406, -0.0168]	[-0.0369, -0.0041]
std.err	0.0065	0.0043	0.0078
t-stat	-3.44	-6.69	-2.64
p-value	0.002	0.003	0.017
Relative Humidity			
coef	-0.0060	-0.0071	-0.0056
95%CI	[-0.0100, -0.0019]	[-0.0105, -0.0038]	[-0.0108, -0.0005]
std.err	0.0019	0.0012	0.0024
t-stat	-3.07	-5.86	-2.32
p-value	0.006	0.004	0.033
Population Density			
coef	0.0262	0.1198	0.0002
95%CI	[-0.0290, 0.0814]	[0.0564, 0.1832]	[-0.0352, 0.0356]
std.err	0.0266	0.0228	0.0168
t-stat	0.98	5.25	0.01
p-value	0.336	0.006	0.991
Percentage over 65			
coef	0.1316	0.3849	0.0612
95%CI	[-1.7302, 1.9933]	[-1.0386, 1.8084]	[-2.3111, 2.4335]
std.err	0.8977	0.5127	1.1244
t-stat	0.15	0.75	0.05

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	Overall	Before Lockdown (Jan 24)	After Lockdown (Jan 24)
p-value	0.885	0.495	0.957
GDP per capita			
coef	0.0048	-0.0110	0.0092
95%CI	[-0.0148, 0.0244]	[-0.0252, 0.0033]	[-0.0114,0.0298]
std.err	0.0095	0.0051	0.0098
t-stat	0.51	-2.13	0.94
p-value	0.616	0.100	0.360
No. of doctors			
coef	-0.0057	-0.0109	-0.0043
95%CI	[-0.0089, -0.0025]	[-0.0162, -0.0056]	[-0.0064,-0.0022]
std.err	0.0015	0.0019	0.0010
t-stat	-3.73	-5.69	-4.35
p-value	0.001	0.005	0.0004
Drop of BMI			
coef	0.3135	-0.4107	0.5146
95%CI	[-0.3290, -0.9559]	[-0.6870, -0.1344]	[-0.0995, 1.1287]
std.err	0.3098	0.0995	0.2911
t-stat	1.01	-4.13	1.77
p-value	0.323	0.015	0.095
Inflow population from Wuhan			
coef	-0.0052	-0.0006	-0.0065
95%CI	[-0.0106, 0.0002]	[-0.0011, -0.0002]	[-0.0128, -0.0002]
std.err	0.0026	0.0002	0.0030
t-stat	-1.99	-3.93	-2.17
p-value	0.059	0.017	0.044
Latitude			
coef	0.0040	0.0082	0.0029
95%CI	[-0.0149, 0.0230]	[-0.0132, 0.0296]	[-0.0213, 0.0271]
std.err	0.0091	0.0077	0.0115

	Overall	**Before Lockdown (Jan 24)**	**After Lockdown (Jan 24)**
t-stat	0.44	1.06	0.25
p-value	0.663	0.347	0.804
Longitude			
coef	-0.0110	-0.0293	-0.0059
95%CI	[-0.0209, -0.0010]	[-0.0579, -0.0008]	[-0.0134, 0.0017]
std.err	0.0048	0.0103	0.0036
t-stat	-2.29	-2.85	-1.64
p-value	0.032	0.046	0.119
const			
coef	1.0925	2.1209	0.8069
95%CI	[0.5059, 1.6792]	[1.5697, 2.6721]	[0.5327, 1.0810]
std.err	0.2829	0.1985	0.1299
t-stat	3.86	10.68	6.21
p-value	0.001	0	0

Table S7: Relationship between Temperature, Relative Humidity, and *R* Values: Robustness Check with the Serial Interval of Mean 7.5 Days and Standard Deviation 3.4 days in Li et al (2020)[2] for Chinese Cities

This table utilizes the estimated serial interval in a previous paper (mean 7.5 days, std 3.4 days)[2] to construct *R* values for China. The table reports the coefficients of the effective reproductive number, *R* values, on an intercept, temperature, relative humidity and control variables in the Fama-MacBeth regressions.

	Overall	**Before Lockdown (Jan 24)**	**After Lockdown (Jan 24)**
R2	0.2843	0.2009	0.3074
Temperature			
coef	-0.0267	-0.0430	-0.0222
95%CI	[-0.0486,-0.0048]	[-0.0694,-0.0165]	[-0.0456,0.0012]
std.err	0.0106	0.0095	0.0111
t-stat	-2.53	-4.52	-2.00
p-value	0.019	0.011	0.061
Relative Humidity			
coef	-0.0076	-0.0104	-0.0068
95%CI	[-0.0121,-0.0031]	[-0.0166,-0.0041]	[-0.0121,-0.0015]
std.err	0.0022	0.0023	0.0025
t-stat	-3.47	-4.59	-2.69
p-value	0.002	0.010	0.015
Population Density			
coef	0.0223	0.1673	-0.0180
95%CI	[-0.0672,0.1118]	[0.0350,0.2996]	[-0.0825,0.0465]
std.err	0.0432	0.0477	0.0306
t-stat	0.52	3.51	-0.59
p-value	0.611	0.025	0.563
Percentage over 65			
coef	-0.7581	0.3976	-1.0791

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	Overall	Before Lockdown (Jan 24)	After Lockdown (Jan 24)
95%CI	[-3.7515,2.2353]	[-2.9474,3.7426]	[-4.8094,2.6511]
std.err	1.4434	1.2048	1.7680
t-stat	-0.53	0.33	-0.61
p-value	0.605	0.758	0.550
GDP per capita			
coef	0.0058	-0.0291	0.0154
95%CI	[-0.0246,0.0361]	[-0.0390,-0.0193]	[-0.0124,0.0433]
std.err	0.0147	0.0035	0.0132
t-stat	0.39	-8.21	1.17
p-value	0.698	0.001	0.258
No. of doctors			
coef	-0.0065	-0.0135	-0.0045
95%CI	[-0.0107,-0.0023]	[-0.0205,-0.0065]	[-0.0067,-0.0024]
std.err	0.0020	0.0025	0.0010
t-stat	-3.22	-5.35	-4.47
p-value	0.004	0.006	0.0003
Drop of BMI			
coef	0.3287	-0.7465	0.6274
95%CI	[-0.5135,1.1709]	[-1.3448,-0.1483]	[-0.1037,1.3585]
std.err	0.4061	0.2155	0.3465
t-stat	0.81	-3.46	1.81
p-value	0.427	0.026	0.088
Inflow population from Wuhan			
coef	-0.0053	-0.0003	-0.0067
95%CI	[-0.0114,0.0008]	[-0.0009,0.0003]	[-0.0139,0.0006]
std.err	0.0029	0.0002	0.0034
t-stat	-1.79	-1.34	-1.94
p-value	0.087	0.250	0.069
Latitude			

	Overall	Before Lockdown (Jan 24)	After Lockdown (Jan 24)
coef	0.0026	0.0045	0.0021
95%CI	[-0.0245,0.0298]	[-0.0518,0.0608]	[-0.0302,0.0344]
std.err	0.0131	0.0203	0.0153
t-stat	0.20	0.22	0.14
p-value	0.843	0.835	0.893
Longitude			
coef	-0.0103	-0.0305	-0.0046
95%CI	[-0.0233,0.0027]	[-0.0796,0.0186]	[-0.0160,0.0067]
std.err	0.0063	0.0177	0.0054
t-stat	-1.64	-1.72	-0.86
p-value	0.116	0.16	0.399
const			
coef	1.0616	2.2036	0.7444
95%CI	[0.4353,1.6879]	[1.431,2.9762]	[0.5063,0.9826]
std.err	0.3020	0.2783	0.1129
t-stat	3.52	7.92	6.60
p-value	0.002	0.001	0

Table S8: Relationship between Temperature, Relative Humidity, and *R* Value: Robustness Check with the Serial Interval of Mean 7.5 Days and Standard Deviation 3.4 days in Li et al (2020)[2] for the U.S. Counties

This table utilizes the estimated serial interval in a previous paper (mean 7.5 days, std 3.4 days)[2] to construct *R* values for the U.S. counties. The table reports the coefficients of the effective reproductive number, *R* value, on an intercept, temperature, relative humidity and control variables in the Fama-MacBeth regressions.

	Overall	**Before Lockdown (April 7)**	**After Lockdown (April 7)**
R2	0.1170	0.1508	0.0760
Temperature			
coef	-0.0199	-0.0271	-0.0113
95%CI	[-0.0330,-0.0069]	[-0.0456,-0.0086]	[-0.0296,0.0071]
std.err	0.0065	0.0089	0.0087
t-stat	-3.08	-3.03	-1.29
p-value	0.004	0.006	0.214
Relative Humidity			
coef	-0.0052	-0.0086	-0.0011
95%CI	[-0.0114,0.0011]	[-0.0169,-0.0003]	[-0.0030,0.0008]
std.err	0.0031	0.0040	0.0009
t-stat	-1.68	-2.14	-1.20
p-value	0.101	0.044	0.244
Population Density			
coef	0.00002	3.00E-05	5.07E-08
95%CI	[-0.00003,0.00006]	[-0.0001,0.0001]	[-2.20e-6,2.30e-6]
std.err	0.00002	4.00E-05	1.07E-06
t-stat	0.73	0.71	0.05
p-value	0.469	0.483	0.963
Percentage over 65			
coef	-0.9733	-1.2685	-0.6159

	Overall	Before Lockdown (April 7)	After Lockdown (April 7)
95%CI	[-1.4465,-0.5000]	[-1.9245,-0.6124]	[-1.0408,-0.1911]
std.err	0.2343	0.3163	0.2022
t-stat	-4.15	-4.01	-3.05
p-value	0.0002	0.001	0.007
Gini			
coef	-1.9913	-2.4119	-1.4822
95%CI	[-3.6305,-0.3521]	[-4.9880,0.1643]	[-2.2360,-0.7285]
std.err	0.8117	1.2422	0.3588
t-stat	-2.45	-1.94	-4.13
p-value	0.018	0.065	0.001
Socio-economic factor			
coef	0.0906	0.1424	0.0279
95%CI	[0.0166,0.1646]	[0.0627,0.2222]	[-0.0112,0.0670]
std.err	0.0366	0.0385	0.0186
t-stat	2.47	3.70	1.50
p-value	0.018	0.001	0.152
No. of ICU beds per capita			
coef	-0.0113	-0.0127	-0.0096
95%CI	[-0.0263,0.0038]	[-0.0367,0.0113]	[-0.0147,-0.0044]
std.err	0.0075	0.0116	0.0025
t-stat	-1.51	-1.10	-3.91
p-value	0.138	0.285	0.001
Fraction of maximum moving distance over normal time			
coef	0.0036	0.0019	0.0056
95%CI	[0.0006,0.0066]	[-0.0023,0.0061]	[0.0043,0.0070]
std.err	0.0015	0.0020	0.0007
t-stat	2.44	0.94	8.67
p-value	0.019	0.356	0
Home-stay minutes			

	Overall	Before Lockdown (April 7)	After Lockdown (April 7)
coef	0.0003	0.0007	-0.0003
95%CI	[-0.0003,0.0008]	[0.0003,0.0011]	[-0.0005,-2e-05]
std.err	0.0003	0.0002	0.0001
t-stat	1.00	3.28	-2.24
p-value	0.321	0.003	0.038
Latitude			
coef	-0.0259	-0.0514	0.0049
95%CI	[-0.0551,0.0032]	[-0.0825,-0.0203]	[-0.0179,0.0277]
std.err	0.0144	0.0150	0.0109
t-stat	-1.80	-3.43	0.45
p-value	0.080	0.002	0.657
Longitude			
coef	0.0070	0.0110	0.0021
95%CI	[0.0019,0.0120]	[0.0059,0.0161]	[0.0003,0.0039]
std.err	0.0025	0.0025	0.0009
t-stat	2.79	4.45	2.50
p-value	0.008	0.0002	0.022
const			
coef	1.7601	2.2325	1.1882
95%CI	[1.1636,2.3566]	[1.6514,2.8137]	[1.1588,1.2177]
std.err	0.2954	0.2802	0.0140
t-stat	5.96	7.97	84.82
p-value	0	0	0

Table S9: Relationship between Temperature, Relative Humidity, and *R* Value: Robustness Check with a social distancing dummy variable for the U.S. Counties.

U.S. states lifted stay-at-home orders, namely a series of social distancing policies, at different times. This table shows the regression results for the U.S. Counties with an additional dummy explanatory variable recording whether the state where a county is located already lifted a stay-at-home order. The regression is estimated by the Fama-MacBeth approach.

	Overall	**Before Lockdown (April 7)**	**After Lockdown (April 7)**
R2	0.1201	0.1403	0.0956
Temperature			
coef	-0.0158	-0.01988	-.01092
95%CI	[-0.0246,-0.0071]	[-0.0300,-0.0097]	[-0.0265,0.0047]
std.err	0.0043	0.0049	0.0074
t-stat	-3.65	-4.07	-1.47
p-value	0.0007	0.0005	0.159
Relative Humidity			
coef	-0.0050	-0.0080	-0.0014
95%CI	[-0.0104,0.0004]	[-0.0151,-0.0010]	[-0.0026,0.0002]
std.err	0.0027	0.0034	0.0006
t-stat	-1.88	-2.37	-2.46
p-value	0.067	0.027	0.024
Population Density			
coef	4.56e-06	7.77e-06	6.89e-07
95%CI	[-1e-5,2e-2]	[-2.53e-5,4.08e-5]	[-1.10e-6,2.48e-6]
std.err	8.34e-06	1.59e-05	8.53e-07
t-stat	0.55	0.49	0.81
p-value	0.587	0.631	0.430
Percentage over 65			
coef	-0.948	-1.1645	-0.6851
95%CI	[-1.3747,-0.5205]	[-1.8362,-0.4927]	[-1.0610,-0.3092]

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	Overall	Before Lockdown (April 7)	After Lockdown (April 7)
std.err	0.2115	0.3239	0.1789
t-stat	-4.48	-3.60	-3.83
p-value	6e-5	0.002	0.001
Gini			
coef	-1.8813	-1.9719	-1.7717
95%CI	[-3.5537,-0.2090]	[-4.5293,0.5855]	[-2.5073,-1.0360]
std.err	0.8281	1.2331	0.3502
t-stat	-2.27	-1.60	-5.06
p-value	0.028	0.124	8e-5
Socio-economic factor			
coef	0.0891	0.1321	0.0371
95%CI	[0.0372,0.1411]	[0.0835,0.1807]	[-0.0048,0.0790]
std.err	0.0257	0.02343	0.0200
t-stat	3.47	5.64	1.86
p-value	0.001	1e-05	0.079
No. of ICU beds per capita			
coef	-0.0096	-0.0084	-0.0111
95%CI	[-0.0235,0.0043]	[-0.0301,0.0133]	[-0.0172,-0.0050]
std.err	0.0069	0.0104	0.0029
t-stat	-1.40	-0.80	-3.83
p-value	0.169	0.430	0.001
Fraction of maximum moving distance over normal time			
coef	0.0041	0.0031	0.0054
95%CI	[0.0016,0.0066]	[-0.0004,0.0067]	[0.0043,0.0065]
std.err	0.0012	0.0017	0.0005
t-stat	3.35	1.82	10.25
p-value	0.002	0.082	0
Home-stay minutes			
coef	0.0003	0.0007	-0.0002

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	Overall	**Before Lockdown (April 7)**	**After Lockdown (April 7)**
95%CI	[-0.0002,0.0007]	[0.0004,0.0010]	[-0.0004,-3e-05]
std.err	0.0002	0.0002	9e-5
t-stat	1.33	4.73	-2.42
p-value	0.191	0.0001	0.026
Latitude			
coef	-0.0182	-0.0348	0.0018
95%CI	[-0.0371,0.0007]	[-0.0510,-0.0185]	[-0.0188,0.0225]
std.err	0.0094	0.0078	0.0098
t-stat	-1.95	-4.43	0.19
p-value	0.058	0.0002	0.854
Longitude			
coef	0.0069	0.0103	0.0029
95%CI	[0.0033,0.0106]	[0.0082,0.0124]	[0.0008,0.0050]
std.err	0.0018	0.0010	0.0010
t-stat	3.82	10.13	2.85
p-value	0.0005	0	0.011
Stay-at-home order			
coef	0.0199	0.0939	-0.0695
95%CI	[-0.0651,0.1049]	[0.0199,0.1678]	[-0.13026,-0.088]
std.err	0.0421	0.0356	0.0289
t-stat	0.47	2.63	-2.40
p-value	0.638	0.015	0.027
const			
coef	1.7395	2.1976	1.1850
95%CI	[1.1800,2.2989]	[1.6645,2.7306]	[1.1695,1.2005]
std.err	0.2770	0.2570	0.0074
t-stat	6.28	8.55	160.27
p-value	0	0	0

Table S10: Relationship between Temperature, Relative Humidity, and *R* Value: Robustness Check with spatial random effect of Chinese cities.

Spatial random effects are introduced in first step of Fama-Macbeth regression to account for spatial correlation. The neighborhood structure is calculated from the Earth distances between cities.

	Overall	Before Lockdown (Jan 24)	After Lockdown (Jan 24)
Temperature			
coef	-0.0212	-0.0269	-0.0196
95%CI	[-0.0361, -0.0063]	[-0.0429, -0.0108]	[-0.0377, -0.0016]
std.err	0.0072	0.0058	0.0085
t-stat	-2.96	-4.65	-2.30
p-value	0.007	0.010	0.034
Relative Humidity			
coef	-0.0045	-0.0074	-0.0037
95%CI	[-0.0090, -0.00003]	[-0.0103, -0.0044]	[-0.0091, 0.0017]
std.err	0.0022	0.0011	0.0026
t-stat	-2.09	-6.90	-1.46
p-value	0.049	0.002	0.162
Population Density			
coef	0.0257	0.1059	0.0034
95%CI	[-0.0197, 0.0711]	[0.0208, 0.1911]	[-0.0200, 0.0268]
std.err	0.0219	0.0307	0.0111
t-stat	1.17	3.45	0.31
p-value	0.253	0.026	0.764
Percentage over 65			
coef	0.0783	0.2110	0.0415
95%CI	[-1.5748, 1.7315]	[-1.1675, 1.5894]	[-2.0603, 2.1432]
std.err	0.7971	0.4965	0.9962
t-stat	0.10	0.42	0.04

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	Overall	Before Lockdown (Jan 24)	After Lockdown (Jan 24)
p-value	0.923	0.693	0.967
GDP per capita			
coef	-0.0022	-0.0155	0.0015
95%CI	[-0.0203, 0.0159]	[-0.0262, -0.0048]	[-0.0187, 0.0218]
std.err	0.0087	0.0038	0.0096
t-stat	-0.25	-4.04	0.16
p-value	0.805	0.016	0.876
No. of doctors			
coef	-0.0056	-0.0101	-0.0044
95%CI	[-0.0083, -0.0030]	[-0.0163, -0.0039]	[-0.0059, -0.0029]
std.err	0.0013	0.0022	0.0007
t-stat	-4.40	-4.52	-6.10
p-value	0.0003	0.011	0.0002
Drop of BMI			
coef	0.2327	-0.3903	0.4057
95%CI	[-0.3638, 0.8291]	[-0.6699, -0.1106]	[-0.2111, 1.0225]
std.err	0.2876	0.1007	0.2924
t-stat	0.81	-3.87	1.39
p-value	0.427	0.018	0.183
Inflow population from Wuhan			
coef	-0.0028	-0.0001	-0.0035
95%CI	[-0.0055, -0.00004]	[-0.0011, 0.0008]	[-0.0063, -0.0007]
std.err	0.0013	0.0003	0.0013
t-stat	-2.11	-0.43	-2.62
p-value	0.047	0.688	0.018
Latitude			
coef	0.0063	0.0076	0.0059
95%CI	[-0.0161, 0.0286]	[-0.0191, 0.0343]	[-0.0221, 0.0339]
std.err	0.0108	0.0096	0.0133

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	Overall	**Before Lockdown (Jan 24)**	**After Lockdown (Jan 24)**
t-stat	0.58	0.79	0.44
p-value	0.566	0.472	0.662
Longitude			
coef	-0.0100	-0.0258	-0.0056
95%CI	[-0.0195, -0.0006]	[-0.0514, -0.0003]	[-0.0141, 0.0028]
std.err	0.0046	0.0092	0.0040
t-stat	-2.20	-2.81	-1.40
p-value	0.039	0.048	0.178
const			
coef	1.1002	2.1148	0.8183
95%CI	[0.5229, 1.6774]	[1.5587, 2.6710]	[0.5551, 1.0815]
std.err	0.2784	0.2003	0.1247
t-stat	3.95	10.56	6.56
p-value	0.001	0	0.0002

Table S11: Relationship between Temperature, Relative Humidity, and *R* Value: Robustness Check with spatial random effect of the U.S. counties.

Spatial random effects are introduced in first step of Fama-Macbeth regression to account for spatial correlation. The neighborhood structure is calculated from the Earth distances between counties.

	Overall	Before Lockdown (April 7)	After Lockdown (April 7)
Temperature			
coef	-0.0136	-0.0135	-0.0136
95%CI	[-0.0215, -0.0057]	[-0.0236, -0.0034]	[-0.0280, 0.0007]
std.err	0.0039	0.0049	0.0068
t-stat	-3.46	-2.78	-2.00
p-value	0.001	0.011	0.061
Relative Humidity			
coef	-0.0052	-0.0072	-0.0029
95%CI	[-0.0095, -0.0010]	[-0.0130, -0.0014]	[-0.0042, -0.0016]
std.err	0.0021	0.0028	0.0006
t-stat	-2.51	-2.57	-4.59
p-value	0.016	0.017	0.0003
Population Density			
coef	3.26e-8	2.98e-6	-3.54e-6
95%CI	[-0.00002, 0.00002]	[-0.00003, 0.00004]	[-5.13e-6, -1.95e-6]
std.err	8.58e-6	0.00002	7.57e-7
t-stat	0.00	0.18	-4.67
p-value	0.997	0.858	0.0002
Percentage over 65			
coef	-0.7988	-1.0894	-0.4471
95%CI	[-1.4330, -0.1647]	[-2.0771, -0.1017]	[-0.7620, -0.1322]
std.err	0.3140	0.4763	0.1499
t-stat	-2.54	-2.29	-2.98

	Overall	Before Lockdown (April 7)	After Lockdown (April 7)
p-value	0.015	0.032	0.008
Gini			
coef	-1.8186	-2.2916	-1.2460
95%CI	[-3.3837, -0.2534]	[-4.5288, -0.0543]	[-2.1425, -0.3495]
std.err	0.7750	1.0788	0.4267
t-stat	-2.35	-2.12	-2.92
p-value	0.024	0.045	0.009
Socio-economic factor			
coef	0.1131	0.1480	0.0708
95%CI	[0.0682, 0.1580]	[0.0903, 0.2056]	[0.0451, 0.0965]
std.err	0.0222	0.0278	0.0122
t-stat	5.08	5.32	5.78
p-value	0.0002	0.0002	0.0002
No. of ICU beds per capita			
coef	-0.0092	-0.0127	-0.0050
95%CI	[-0.0238, 0.0054]	[-0.0359, 0.0105]	[-0.0101, 0.0002]
std.err	0.0072	0.0112	0.0025
t-stat	-1.27	-1.14	-2.01
p-value	0.210	0.267	0.059
Fraction of maximum moving distance over normal time			
coef	0.0040	0.0024	0.0059
95%CI	[0.0012, 0.0068]	[-0.0014, 0.0063]	[0.0054, 0.0064]
std.err	0.0014	0.0019	0.0002
t-stat	2.93	1.30	25.03
p-value	0.005	0.207	0
Home-stay minutes			
coef	0.0003	0.0005	0.00002
95%CI	[0.00002, 0.0006]	[0.0001, 0.0009]	[-0.0002, 0.0002]
std.err	0.0001	0.0002	0.0001

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	Overall	Before Lockdown (April 7)	After Lockdown (April 7)
t-stat	2.15	2.81	0.19
p-value	0.038	0.010	0.851
Latitude			
coef	-0.0152	-0.0278	-0.00004
95%CI	[-0.0308, 0.0003]	[-0.0423, -0.0133]	[-0.0208, 0.0207]
std.err	0.0077	0.0070	0.0099
t-stat	-1.98	-3.97	-0.00
p-value	0.055	0.001	0.997
Longitude			
coef	0.0060	0.0084	0.0032
95%CI	[0.0033, 0.0088]	[0.0064, 0.0104]	[0.0015, 0.0049]
std.err	0.0014	0.0010	0.0008
t-stat	4.45	8.78	3.86
p-value	0.0003	0	0.001
const			
coef	1.7377	2.2018	1.1759
95%CI	[1.1715, 2.3039]	[1.6623, 2.7413]	[1.1594, 1.1923]
std.err	0.2803	0.2601	0.0078
t-stat	6.20	8.46	150.10
p-value	0	0	0

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