PEER REVIEW HISTORY

ARTICLE DETAILS

TITLE (PROVISIONAL)	Impact of temperature and relative humidity on the transmission of COVID-19: A modeling study in China and the U.S.
AUTHORS	Wang, Jingyuan; Tang, Ke; Feng, Kai; Lin, Xin; Lv, Weifeng; Chen, Kun; Wang, Fei

VERSION 1 – REVIEW

REVIEWER	DAVID NADLER PRATA Universidade Federal do Tocantins, Brazil
REVIEW RETURNED	04-Sep-2020

GENERAL COMMENTS	As emphasized by the authors, the study seems to be a novel application of the Fama-Macbeth (financial) method in urgent public health and epidemiological problems. For this reason, it is essential to compare this methodology results with traditional environmental methods of data analysis and report outcomes. Otherwise, compare the results with other studies already published. Another issue. Usually, in traditional methods, there is a result of a cross-sectional correlation and another result for time-series correlation, and these correlations can be the opposite. The question is what that means both results together in an environmental context? how to interpret it? Some claims need careful consideration, like "An increase of roughly 30°C in temperature and 25% in relative humidity from winter to summer reduce the R value by 0.69 and 0.20 respectively, which would altogether lower down R value by 0.89." As we know there is an interaction between temperature and relative humidity, it is reasonable to not simply add 0.69 and 0.20. At the topic "Temperature, Relative Humidity, and Effective Reproductive Numbers", the results of "before the lockdown" are repeated. It is reasonable to avoid text repetition.

REVIEWER	Dr. Bilal Hubei University of Economics, Wuhan, China
REVIEW RETURNED	25-Sep-2020

GENERAL COMMENTS	After reading it carefully, I suggest Major Revision after authors introduce the following changes before this paper can be considered for publication. 1. I suggest that the authors should introduce further literature to evaluate and incorporate the following references (updated) in the literature to create a better understanding. a) Bashir, M. F., Ma, B., Komal, B., Bashir, M. A., Tan, D., & Bashir, M. (2020). Correlation between climate indicators and

	COVID-19 pandemic in New York, USA. Science of The Total Environment, 138835. b) Bilal, Bashir, M. F., Benghoul, M., Numan, U., Shakoor, A., Komal, B., Bashir, M.A, Bashir, M., and Tan, D. (2020). Environmental pollution and COVID-19 outbreak: insights from Germany. Air Quality, Atmosphere & Health. doi:10.1007/s11869-020-00893-9. c) Bashir, M. F., Ma, B., & Shahzad, L. (2020). A brief review of socio-economic and environmental impact of Covid-19. Air Quality, Atmosphere & Health. doi:10.1007/s11869-020-00894-8 d) Collivignarelli, M. C., Abbà, A., Bertanza, G., Pedrazzani, R., Ricciardi, P., & Miino, M. C. (2020). Lockdown for CoViD-2019 in Milan: What are the effects on air quality?. Science of The Total Environment, 732, 139280. e) Ní Ghráinne, B. (2020). Covid-19, Border Closures, and International Law. Border Closures, and International Law. 2. Introduction and results section discussion needs significant improvement with better explanation. 3. The authors should provide further clarification about how this research can help future studies on the subject. 4. Further grammatical and spell-checking should eliminate minor mistakes.

REVIEWER	Wei Li Shandong University, China
REVIEW RETURNED	16-Nov-2020

GENERAL COMMENTS	1 Now there are many papers about investigating the relationship between COVID-19 transmission and meteorological factors, so the author may briefly mention the advantages of the method in this paper over other methods. 2 R value is influenced by the previous R value, did authors consider the relationship between R value and previous R value? 3 In China, the implementation of the lockdown policy is relatively thorough. So, the lockdown policy didn't influence on the effect of the model. Did the lockdown policy that varies from state to state in the United States influence the effect of the model of the United States? 4 In discussion, "Although we use different datasets (symptom-onset data for Chinese cities and confirmed cases data for the U.S. counties) for different countries, we obtain consistent estimates. This result also aligns with the evidence that high temperature and high humidity can reduce the transmission of influenza [30], which can be explained by two potential reasons." The Control Variables of model in China are different from those of model in the United States. If the Control Variables of model in China are as same as those of model in the United States, Is the result the same as above 5 In discussion, The author can refer to not only the relationship between infectious diseases and meteorological factors, but also the relationship between some diseases and meteorological factors, and refer to articles like "Cai Chen 2020 Environmental science and pollution research".

VERSION 1 – AUTHOR RESPONSE

Response to Reviewer # 1

Q1: Compare Fama-MacBeth regression results with traditional environmental methods of data analysis and report outcomes. Otherwise, compare the results with other studies already published.

A1: We thank the referee for this valuable suggestion. There are only very short nonintervened periods before large-scale public health interventions imposed in China and the US. For example, in China, the nationwide intervention policies were implemented on Jan 24, 2020, which left us with only 5 days of non-intervened data where the transmissibility of COVID-19 is influenced by the natural weather conditions. [1]

Traditional methods usually require long time-series data (many years' data) to get credible results between time series, especially for trended ones.[2] Therefore, classical time-series or panel regressions are not appropriate for our study.

Following the referee's advice, we, hence, need to compare our results with related studies about meteorological factors and COVID-19 transmissibility that have already been published. Although there are some studies on this topic, we are certainly the first one (on SSRN on March 9, 2020) documenting a negative relationship between COVID-19 transmissibility and the temperature/humidity. There is currently no consensus on the impact of meteorological factors on COVID-19 transmissibility. For example, Merow et al. state that ultraviolet light is associated with a decrease in COVID-19 growth rate [5]. Yao et al. claim that temperature and ultraviolet light are not related to COVID-19 transmission [6] while Al-Rousan et al. and Xie et al. come up with a positive association between temperature and daily confirmed cases [7,8]. The obvious difference in these results suggests that these published studies have certain limitations in their research methods. We have also added those references in the main text, please refer to the modified Introduction and Discussion sections of our article about the details.

Q2: Usually, in traditional methods, there is a result of a cross-sectional correlation and another result for time-series correlation, and these correlations can be the opposite. The question is what that means both results together in an environmental context? how to interpret it?

A2: We thank the referee for raising this important question. This question is directly related to our choice of method. We use Fama-MacBeth regression framework, which first runs cross-sectional regressions and then calculates the average of cross-sectional coefficients across time (with adjustment on serial correlations using the Newey West methodology). The Fama-MacBeth regression essentially focuses more on the crosssectional correlation of the effective reproductive numbers (R value) and temperature/ relative humidity. This fits in our strategy of "trading space for time" in this paper.

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1 Note that when people have to stay at home during the lockdown periods, natural weather conditions tend to have a less significant role in influencing the transmissibility of COVID-19.

2 For example, study from Hemmes *et al*. investigated the seasonality of influenza using weekly recorded data from 1946 to 1957 [1]. Benjamin *et al*. used 6 years of data on weekly incidence of flu to investigate the impact of humidity on intensity of influenza [2]. Studies from Shaman *et al*. also involved 30 years of data to check the association between humidity and influenza-related mortality [3]. Although we can access more frequently-sampled data on COVID-19 (e.g. daily data of mortality is available in most countries) than previous study, Pedroni has shown that power for testing a cointegration relationship is affected by the time span of data, rather than the frequency of sampling [4]. So, the long-term time series data is still in need for traditional methods.

Regressing time-series data directly is not suitable in our study, because the timeseries of R values and temperature all have trends. Particularly, R values trend down in our sample, and the temperature trends up (shown in Figure R1 and Figure R2). Although the correlation between R value's trend and temperature's trend is negative, which is consistent with the main results in our paper, we do not trust the time-series correlations because those (trending) non-stationary time-series will cause a spurious relationship [9]. Note that although non-stationary problems can be dealt with the cointegration analysis, testing cointegration requires long-run time series that cover many years [4]. This, thus, is not doable, as the emergent outbreak of COVID-19 only offers us a quite short time-series dataset even up to now. However, as the COVID-19 has spread to many cities (counties), we have abundant cross-sectional samples, which gives us a good opportunity to study the cross-sectional correlation, i.e. trading space for time.

[Figure R1 and R2 about here]

Q3: Some claims need careful consideration, like "An increase of roughly 30°C in temperature and 25% in relative humidity from winter to summer reduce the R value by 0.69 and 0.20 respectively, which would altogether lower down R value by 0.89."
A3: Following the referee's suggestion, we have deleted the above-mentioned sentence from the text.

Q4: At the topic "Temperature, Relative Humidity, and Effective Reproductive Numbers", the results of "before the lockdown" are repeated. It is reasonable to avoid text repetition.
A4: Thanks indeed for pointing this out! We have revised this part and deleted the repeated results in the main text.

Response to Reviewer #2

Q1: I suggest that the authors should introduce further literature to evaluate and incorporate the following references (updated) in the literature to create a better understanding.

a) Bashir, M. F., Ma, B., Komal, B., Bashir, M. A., Tan, D., & Bashir, M. (2020). Correlation between climate indicators and COVID-19 pandemic in New York, USA. Science of The Total Environment, 138835.

b) Bilal, Bashir, M. F., Benghoul, M., Numan, U., Shakoor, A., Komal, B., Bashir, M.A, Bashir, M., and Tan, D. (2020). Environmental pollution and COVID19 outbreak: insights from Germany. Air Quality, Atmosphere & Health. doi:10.1007/s11869-020-00893-9.

c) Bashir, M. F., Ma, B., & Shahzad, L. (2020). A brief review of socio-economic and environmental impact of Covid-19. Air Quality, Atmosphere & Health. doi:10.1007/s11869-020-00894-8

d) Collivignarelli, M. C., Abbà, A., Bertanza, G., Pedrazzani, R., Ricciardi, P., & Miino, M. C. (2020). Lockdown for CoViD-2019 in Milan: What are the effects on air quality?. Science of The Total Environment, 732, 139280.

e) Ní Ghráinne, B. (2020). Covid-19, Border Closures, and International Law. Border Closures, and International Law.

A1: We have found these references to be very helpful in explaining the objective and background of our study and thus cited these references in our paper.

Q2: Introduction and results section discussion needs significant improvement with better explanation.
A2: Thank you for your suggestion. We have revised these sections attentively; the major changes are summarized as follows:

1) We have revised the Introduction and Results sections to avoid repetitive and confusing statements. We have also included some explanatory languages and added some examples in both sections.

2) We have conducted a more thorough literature review and added more references directly related to the impact of COVID-19 and the association between meteorological factors and COVID-19 transmissibility in the Introduction section. Those references help to better illustrate the state-of-art research on related problems and showcase the importance of our study.

Q3: The authors should provide further clarification about how this research can help future studies on the subject.
A3: Thanks for this suggestion. Our research can help future studies in the following aspects:

1) Our preprint version (on SSRN on March 9, 2020) was the first to find a robust negative correlation between temperature / relative humidity and COVID-19 transmissibility. This paper has some potential to inspire new studies on the impact of meteorological factors on the transmission of COVID-19.

2) The main results of our research are likely to push researchers to further study the underlying mechanism of how temperature and relative humidity impact the transmissibility of COVID-19.

3) We proposed a novel application of the Fama-MacBeth regression framework for tackling urgent public health problems. This framework is based on the strategy of "trading space for time" that only requires short time series to carry out the analysis, and the use of this framework is widely adoptable to other areas.

Q4: Further grammatical and spell-checking should eliminate minor mistakes.
A4: Thank you for your suggestion. We would like to apologize for grammatical and spelling mistakes. Per your suggestion, we have used a professional editing service to improve the English writing of the paper (certificate attached).

Response to Reviewer #3

Q1: Now there are many papers about investigating the relationship between COVID-19 transmission and meteorological factors, so the author may briefly mention the advantages of the method in this paper over other methods.
A1: Thanks for raising this question. Following your advice, we have investigated papers on COVID-19 transmission and meteorological factors, and made a comparison between ours and theirs in the Discussion section. Our method has several advantages compared with other studies. These advantages can be summarized as follows:

1) We propose a novel application of the Fama-MacBeth regression framework. The R values of our study periods have a decreasing trend and as shown in Figure R1 and Figure R2, the temperature of the same periods generally has an increasing trend. Directly using these non-stationary time series in a regression may get a spurious relationship [4]. However, our Fama-MacBeth framework is still applicable because it mainly runs a cross-sectional regression for each period. For details, please refer to the Supplementary Material of the paper.

2) We consider more variables that may influence COVID-19 transmissibility.

As for other studies about the relationship between COVID-19 transmission and meteorological factors, Merow et al. investigate the influence of meteorological conditions on COVID-19 infections with only population density and proportion over 65 years as control variables [5]. A previous study by Yao et al. has announced no association between COVID-19 transmission and temperature, however, they only use a rough temperature measure (a 2-month averaged temperature) for analysis, and the trends of temperature are not considered [6]. Xie et al. present positive (opposite to our results) relationships between temperature and COVID-19 case numbers [8]. However, the demographic factors for cities are not incorporated as controls, and the effectiveness of non-stationary time series for the panel regression methods they use is not explicitly discussed.

Q2: R value is influenced by the previous R value, did authors consider the relationship between R value and previous R value?

A2: Thanks for the insightful question! We do not use the previous R value in the regression for the following reasons:

1) If R(t-1) is used as a control variable, the magnitudes of estimates on temperature/relative humidity will be biased. There are correlations between R(t-1) and temperature(t-1) (demonstrated in this paper); and temperature(t-1) and temperature(t) are certainly related, therefore, R(t-1) correlates with temperature(t). Hence, adding R(t-1) in the regression will certainly dilute the influence of temperature(t) on R(t), and thus twist the regression coefficient of R(t) on temperature/relative humidity.

2) The R value is measured using the cases in a window of the prior several days. Therefore, for daily observations as in our paper, the sample windows for measuring R(t-1) and R(t) are overlapped, and hence R(t) and R(t-1) are mechanically correlated due to data overlapping. Therefore, it is not appropriate to add R(t-1) in the regression.

Q3: In China, the implementation of the lockdown policy is relatively thorough. So, the lockdown policy didn't influence on the effect of the model. Did the lockdown policy that varies from state to state in the United States influence the effect of the model of the United States?

A3: We thank the referee for pointing this out. The main reason for distinguishing between before lockdown and after lockdown is that the indoor temperature and humidity are relatively constant, so if people stay at home most of the time, the outdoor temperature and humidity will not affect the spread of the virus. In addition, after the lockdown, people got less chance to contact each other, this can also weaken the impact of outdoor temperature and humidity. If some states lockdown earlier, the regression results tend to be less significant. Even though, we still get significant results in our regression, which confirms the robustness of our results.

To double-check the influence of the lockdown policies, we have added a dummy variable for whether there was a stay-at-home policy on a certain date of a certain U.S. state. The new regression results presented in Table R1 in this document are consistent with the results in the paper (also see Table S8 in the supplementary materials). Note that the dates of the state-wide announcement of stay-at-home policy are collected from https://www.kff.org/policy-watch/lifting-social-distancing-measures-in-america-stateactions-metrics/ .

[Table R1 about here]

Q4: The Control Variables of model in China are different from those of model in the United States. If the Control Variables of model in China are as same as those of model in the United States, Is the result the same as above？

A4: We thank the referee for raising this question. Although the exact variable is different, the basic categories of variables are consistent in both countries: demographics, socio-economic status, geographical variables, healthcare and human mobility status. Due to the lack of available data, we could not collect the same variables of each category for the two countries. We, therefore, perform additional regressions using only the same control variables in both countries. The additional regression results in Table R2 and Table R3 show negative correlations between temperature/relative humidity and COVID-19 transmissibility, consistent with the results in our paper.

[Table R2 and R3 about here]

Q5: In discussion, the author can refer to not only the relationship between infectious diseases and meteorological factors, but also the relationship between some diseases and meteorological factors, and refer to articles like "Cai Chen 2020
Environmental science and pollution research".

A5: Following the referee's suggestion, we have cited the above-mentioned paper in the Introduction section.

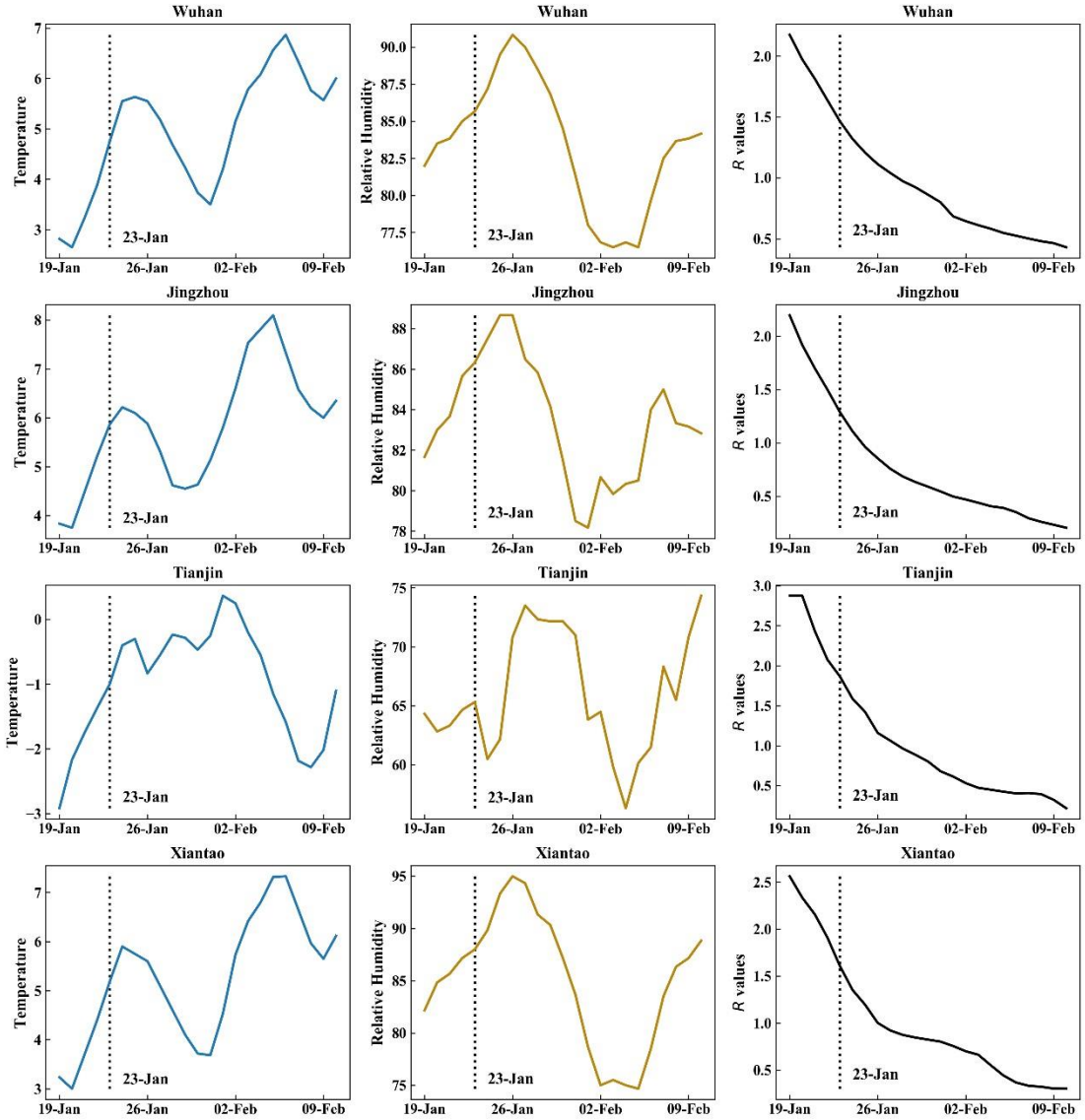

Figure R1. Temperature, relative humidity and R values for cities in China

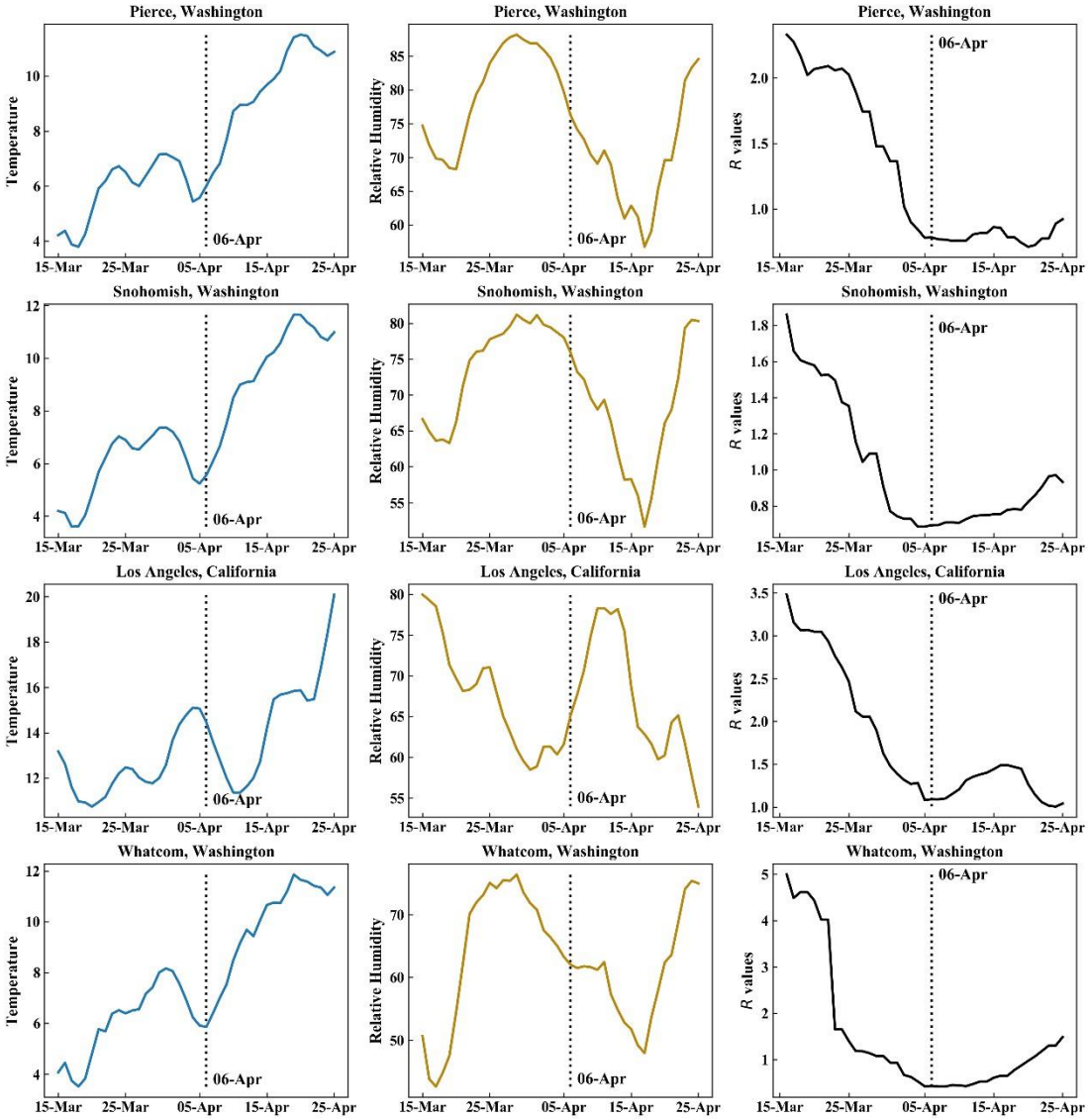

Fig. R2. Temperature, Relative humidity and R values for counties in the U.S.

Table R1: Fama-MacBeth Regression with the stay-at-home dummy variable for the U.S. Counties

	Overall	Before Lockdown (Apr 7)	After Lockdown (Apr 7)
Temperature			
coef	-0.0158	-0.0199	-0.0109
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

Table R2: Fama-MacBeth Regression using the same control variables for Chinese Cities

	Overall	Before Lockdown (Jan 24)	After Lockdown (Jan 24)
Temperature coef	-0.0387	-0.0410	-0.0381
95%CI	[-0.0452,-0.0322]	[-0.0559,-0.0260]	[-0.0460,-0.0301]
std.err	0.0031	0.0054	0.0038
t-stat	-12.31	-7.63	-10.10
p-value	0	0.002	0
Relative Humidity coef	-0.0077	-0.0119	-0.0065
95%CI	[-0.0125,-0.0029]	[-0.0163,-0.0076]	[-0.0117,-0.0014]
std.err	0.0023	0.0016	0.0024
t-stat	-3.34	-7.63	-2.67
p-value	0.003	0.002	0.016

Table R3: Fama-MacBeth Regression using the same control variables for the U.S. Counties

	Overall	Before Lockdown (Apr 7)	After Lockdown (Apr 7)
Temperature coef	-0.0098	-0.0108	-0.0086
95%CI	[-0.0192,-0.0005]	[-0.0186,-0.0030]	[-0.0284,0.112]

std.err	0.0046	0.0038	0.0095
t-stat	-2.12	-2.88	-0.91
p-value	0.040	0.009	0.374
Relative Humidity coef	-0.0054	-0.0085	-0.0017
95%CI	[-0.0108,-7.96E-5]	[-0.0154,-0.0016]	[-0.0032,-0.0003]
std.err	0.0026	0.0033	0.0007
t-stat	-2.05	-2.54	-2.54
p-value	0.047	0.019	0.021

VERSION 2 – REVIEW

REVIEWER	Bilal Hubei University of Economics, China.
REVIEW RETURNED	20-Jan-2021

GENERAL COMMENTS	Thanks! Paper can be published.

REVIEWER	Wei Li China
REVIEW RETURNED	18-Jan-2021

GENERAL COMMENTS	After the modification, the author answered the questions I raised in detail