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Abstract
I investigate whether the cross-sectional data on cumulative (symptomatic) cases of coronavirus in the 48 contiguous states of the U.S. at the end of March 2020 provide any evidence that the rate of transmission of the virus declines at higher temperatures. Average temperatures in March varied from 30 to 71 degrees Fahrenheit in the 48 states. Controlling for other relevant factors, including population density and the availability of testing, I find no evidence that a higher average temperature in a state reduced the incidence of cumulative cases/capita of the virus in the state. These results provide no indication that seasonal increases in temperature will cause the coronavirus epidemic to disappear in the summer.

Key Words
Coronavirus, temperature, community spread, U.S.

JEL classification
I12, I18

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I. Introduction

Anecdotal and some empirical evidence from Asia indicates that the coronavirus spreads more rapidly in colder, drier climates [Wang, Tang, Feng, and Weifeng, 2020]. But the effect of changes in temperature and humidity on transmission of the virus in Asian countries will not necessarily be the same in Western countries, since the climate, the culture, and the prevalence of heating and air-conditioning are different.

In this paper I present the results of a statistical analysis of the effect of average March temperatures in the 48 contiguous U.S. states on the estimated cumulative number of cases/capita of coronavirus in each state at the end of March. As will be discussed below, due to the lag between contagion and the reporting of cases, I use the cumulative number of cases by state reported on April 10th as my measure of the number of cases that existed on March 31st.

In March 2020 average temperatures in the 48 states varied from 30 to 71 degrees Fahrenheit [NOAA, 2020]. I find that these differences in temperature had no effect on the estimated cumulative number of (eventual symptomatic) cases that existed across states at the end of March.

Temperatures in most U.S. states in the summer months exceed the range examined in this study, but some northern states have average July temperatures below the highest average temperature in this study [NOAA, 2020]. So the temperature range for the 48 states in March is relevant for the northern states in the summer months.

The results in this study provide no evidence to support the hypothesis that the incidence of coronavirus in the U.S. will decrease due to the higher average temperatures in the summer months. The model successfully explains 75% of the variation in cases/capita, but differences in temperature have no effect.

II. Methodology

During March 2020 several groups began tracking all reported cases of coronavirus in the U.S. by state and publishing their findings online, with updates every few hours. For several reasons these data are not an accurate representation of either the total number of cases or of the date when the cases occurred. The level of testing was not consistent across states, and for several weeks the results from the tests were delivered to medical service providers with a delay that varied widely. Cases with mild or no symptoms generally were not tested, so the reported cases are a substantial underestimate of the actual cases in each state. In addition, contagion occurred considerably earlier than the time of reporting, so until recently the number of reported cases measured the spread of the disease weeks earlier.

The first confirmed case in the U.S. occurred in Washington State on January 19, 2020 in a traveler from Wuhan, China [Hoshue et al., 2020]. The epidemic began in Wuhan about a month earlier. Since both San Francisco and New York had direct flights from Wuhan until January 23, 2020, the initial transmission of the virus to other cities in the U.S. likely occurred at about this time, even though its arrival was not discovered in these locations until later. Given the large numbers of Chinese tourists who continued to arrive from China until January 31st and their widespread destinations in the U.S., it is extremely likely that other major U.S. tourist destinations, such as

Orlando, Florida, and Los Angeles, California, experienced transmission of the disease in January 2020.

Researchers have determined that the coronavirus was circulating in New York in mid-February and that travelers brought in strains of the virus that originated primarily in Europe [Zimmer, 2020]. These findings provide evidence that tourists and business travelers likely had spread the virus from China and Europe to numerous locations in the U.S. by early February.

Due to the lag between contagion and the onset of symptoms, as well as to the delay in obtaining a test and receiving the results, the cumulative cases of coronavirus reported in March measure the earlier incidence of the portion of cases that would become symptomatic weeks later. The CDC's analysis shows that the onset of symptoms for cases reported at the end of March occurred from 0 to 4 weeks earlier, with an average lag of about two weeks [CDC, 2020]. Other analyses indicate that the average incubation period between contagion and the onset of symptoms is 5.1 days [Lauer et al., 2020]. This implies that the average time lag between contagion and the symptomatic cases reported at the end of March was about 19 days.

In early April the lag between the onset of symptoms and the reporting of test results became much shorter, as the public's awareness of the virus became widespread and private laboratoties began to perform large numbers of tests on a more expedited basis. The reported lag for test results from LabCorp and Quest Diagnostics on April 8th was 3-4 days [Strickler and Kaplan, 2020]. The implication is that time lag between contagion and test results in much of the country had declined to 9-10 days.

Consistent with this estimate of the lag, in this analysis I use the number of cases reported by Jin [2020] on April 10, 2020 to measure the cumulative transmission of the virus by state in the U.S. at the end of March. Implicitly, the transmission of the virus associated with these reported cases occurred between late January and the end of March. I use Jin's data on reported cases rather than the *New York Times*'s data to ensure consistency between the reported cases and Jin's data on total tests in each state. The two data sets on reported cases are similar on April 10th, but the number of cases is not identical for all states.

Information on the testing process across states indicates that the reported cases generally do not include the asymptomatic cases of the virus, although some of these cases are likely to be included in states with more extensive testing. As long as the asymptomatic share is similar across states, the exclusion of these cases from the data should not affect the magnitude or the statistical significance of the effect of temperature on the transmission of the virus.

In the complete model I estimate the log(cases/capita) in the 48 states as a function of the following six variables:

- Log of average temperature in degrees Fahrenheit
- Log of population density in the state
- Log of air travel arrivals/capita in the state
- Dummy variable for New York/New Jersey
- Tests/thousand inhabitants in the state

- Dummy variable for states with a governor who is a Democrat

I use either the rate or the log of the rate for each variable, depending on which form provides the best fit of the data.

I use NOAA data on average March 2020 temperatures for each state for my analysis of the effect of temperature on transmission, although I also examine the effect of including February temperatures [NOAA, 2020]. For some of the more rural states, the March temperatures are more relevant, since the virus likely did not arrive there until later.

Transmission is likely to have been delayed in states without major cities or tourist destinations and is likely to have spread more slowly in less densely-populated states. I include variables in the regression for population density and air travel arrivals per capita to control for state characteristics other than temperature that could affect the rate of transmission.

I include a dummy variable for New York and New Jersey to control for the possibility that these states have higher transmission rates due to the particularly high population density in New York City. This density and the unusually high reliance on public transportation is likely to raise transmission rates above levels in other states.

The number of reported cases in each state is affected by the availability of testing. Jin [2020] provides data on the cumulative number of tests performed in each state. I use the data on numbers of completed tests published online on April 10th as my measure of the incidence of testing in each state at the time the cumulative tests were reported. I use these data to create a variable for tests/capita to control for differences in testing rates across states.

The number of cases is affected by the degree of earlier social distancing required in each state. Actions taken to require social distancing only began in late March, so they might not have had much effect during the period of the analysis. Any differences in these conditions across states may have been affected by the Governors' political affiliation, since anecdotal evidence suggests that Republican governors initially took the threat of the virus less seriously than Democrat governors. I include a dummy variable to control for whether a Governor was a Democrat. This political affiliation would be expected to have a negative effect on reported cases of the disease.

The data used in the study are included in the Appendix.

III. Results

The results from the analysis are shown in Table 1. Column 1 shows the effect of average temperature alone. The subsequent columns show the effect when additional variables are added to the model. Column 6 presents the results for the complete model.

Table 1 **Effect of Temperature on Coronavirus Cases Across States in the U.S.** Dependent Variable is Log(Cases/Million Inhabitants)						
	1	2	3	4	5	6
Sample	48	48	48	48	48	48
Log(Avg March Temperature)	0.15 (.51)	-0.66 (.43)	-0.66 (.43)	-0.38 (.39)	-0.06 (.30)	-0.04 (.31)
Log(Population Density)		0.42* (.08)	0.42* (.08)	0.32* (.07)	0.28* (.06)	0.28* (.06)
Air travel arrivals/capita			0.06 (.07)	0.05 (.06)	0.06 (.04)	0.06 (.05)
NY/NJ Dummy				1.61* (.44)	0.78 (.36)	0.77 (.37)
Tests/Thousand Inhabitants					0.10* (.02)	0.10* (.02)
Governor is a Democrat						0.03 (.14)
Constant	6.11* (1.95)	7.25* (1.55)	7.15* (1.55)	6.48* (1.38)	4.61* (1.09)	4.55* (1.14)
R^2	.00	.40	.41	.55	.75	.75
*Statistically significant at the 1% level						

The model in column 1 shows that cases/capita and average temperature have very little correlation across the 48 states. Differences in temperature alone cannot explain any of the differences in the number of reported coronavirus cases across states at the end of March.

Column 2 shows the importance of a state's population density on the transmission of the virus. The explained variation in log(cases/capita) rises from 0 to 40% with the addition of the log of this variable. The coefficient on the variable is highly statistically significant and remains so in all the subsequent models. With the addition of this variable, the effect of log(temperature) on transmission of the virus becomes negative. The coefficient on temperature is an elasticity, with a non-trivial estimated value of -0.66, but the coefficient is not statistically significant at the 5% level.

Column 3 shows the effect of adding air travel arrivals per capita to the model. The effect of more arrivals on cases/capita is positive, but the effect is small and not statistically significant. The effect of temperature on the transmission of the virus remains unchanged.

Column 4 shows the effect of adding a dummy variable for New York/New Jersey. The coefficient is statistically significant at the 1% level and substantially raises the explained variation in the reported cases. It seems likely that some unspecified characteristic of New York City, perhaps it's very high population density, is implicitly raising the transmission rate of the virus in these two states beyond that in other states. Simultaneously, the coefficient on temperature declines and becomes much less statistically significant.

Column 5 shows the effect of controlling for the level of testing on the number of reported cases. The effect of more testing is positive, as expected, and very statistically significant. The explained variation in reported cases rises from 55% to 75% with the addition of the testing rate variable. Importantly, any negative effect of temperature on the number of cases of the virus almost completely disappears. Population density remains statistically significant at the 1% level, while the coefficient on the NY/NJ dummy variable declines but remains significant at the 5% level.

Column 6 shows the effect of adding the Governors' political affiliation to the model. Their affiliation has no effect on the number of reported cases in the states.

I also examined the effect of using the average temperatures in both February and March rather than the average temperatures in March in the analysis. Although not shown, the effect of average temperature is similar when the average for both months is used, but the coefficient is even smaller and even less statistically significant than when using average March temperatures.

IV. Conclusions

There is anecdotal and some empirical evidence from studies in Asia that higher temperatures and higher humidity reduce the rate of transmission of the coronavirus. In this study I examine whether there is any evidence that higher temperatures in the U.S. reduced the rate of transmission of the virus across the 48 states over the February – March 2020 period.

I find no evidence that higher temperatures reduced the number of cases over this period. The estimated coefficient provides an elasticity of -0.06 for the effect of changes in temperature on changes in reported cases, with virtually no statistical significance. This estimate is created using a range of average temperatures from 29.7 to 71.1 degrees Fahrenheit. Although summer temperatures are higher than these temperatures in many states, the highest average temperature in the study is similar to the average summer temperatures (day and night) in many northern states.

These results provide no evidence that higher summer temperatures will have any effect on transmission of the coronavirus in the U.S. If there is any effect at temperatures slightly higher than those examined here, it is unlikely that it would be very large, given the complete absence of any effect in this study.

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Appendix
Data Used in the Analysis

States	Cases per MM pop	March Temp	Pop Density	Air Trav per cap	Tests per M pop	NY/NJ Dummy	Democrat Governor
Alabama	610.8	63.3	95.8	0.481	4.3	0	0
Arizona	455.8	51	60.1	3.262	5.5	0	0
Arkansas	393.2	56.4	57.2	0.586	5.7	0	0
California	497.4	47.9	251	2.275	4.2	0	1
Colorado	1193.1	38.7	52.6	4.976	6.0	0	1
Connecticut	2934.7	41.5	741.2	0.757	10.1	0	1
Delaware	1401.8	49.8	484.1	0.056	12.4	0	1
Florida	864.8	71.1	375.9	3.479	8.0	0	0
Georgia	1124.1	63	176.4	4.555	4.5	0	0
Idaho	817.6	35.2	20	0.981	7.9	0	0
Illinois	1390.9	44.6	231.4	3.376	6.8	0	1
Indiana	1043.4	44.6	184.6	0.652	5.3	0	0
Iowa	444.3	40.4	55.9	0.541	5.1	0	0
Kansas	400.5	47.9	35.6	0.293	3.9	0	1
Kentucky	382.6	51.4	111.4	1.135	5.5	0	1
Louisiana	4122.1	67.3	107.2	1.251	19.8	0	1
Maine	440.8	29.7	43.1	0.837	5.0	0	1
Maryland	1160.1	49.3	614.5	1.853	7.4	0	0
Massachusetts	3086.9	40.4	866.6	2.228	15.1	0	0
Michigan	2296.1	35	174.7	1.818	7.3	0	1
Minnesota	243.4	30.6	69	3.028	6.2	0	1
Mississippi	825.1	64	63.8	0.354	7.1	0	0
Missouri	624.5	48.8	88.3	1.913	6.7	0	0
Montana	353.4	31.7	7.1	1.602	8.0	0	1
Nebraska	334.9	41.1	24.7	1.163	4.9	0	0
Nevada	893.9	40.4	26.3	7.521	7.9	0	1
New Hampshire	615.5	34.2	148.4	0.904	7.5	0	0
New Jersey	6093.8	46.3	1,207.8	2.036	12.7	1	1
New Mexico	523.2	47.9	17.2	1.253	13.0	0	1
New York	8613.5	37.2	419.3	2.354	21.1	1	1
North Carolina	389.1	56.1	206.2	2.791	5.7	0	1
North Dakota	367.3	29.8	11	1.513	12.7	0	0
Ohio	506.1	44.9	283.6	0.834	5.0	0	0
Oklahoma	458.7	55.4	57	0.809	5.7	0	0
Oregon	327.9	38.8	42	2.100	6.4	0	1
Pennsylvania	1560.6	42.6	285.7	1.572	8.8	0	1
Rhode Island	1907.6	42.4	1,010.8	1.804	13.5	0	1
South Carolina	626.0	60.8	162.6	0.772	5.8	0	0

South Dakota	624.4	36.4	11.3	0.911	8.9	0	0
Tennessee	736.6	54.9	160.1	1.318	9.5	0	0
Texas	424.9	63.2	104.9	2.579	4.2	0	0
Utah	701.6	40.5	36.5	3.287	13.6	0	0
Vermont	1084.6	33	67.7	0.976	13.1	0	0
Virginia	537.9	51.8	211.7	2.919	4.2	0	1
Washington	1340.0	38.4	107.8	2.678	13.0	0	1
West Virginia	300.4	47.7	76.6	0.211	7.9	0	0
Wisconsin	531.6	34.2	106.3	0.837	6.3	0	1
Wyoming	546.0	33.2	6	0.908	8.6	0	0