POLICY BRIEF

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CORONAVIRUS AND TEMPERATURE

Note: the data and analysis in this brief will be updated as the pandemic evolves

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Coronavirus and Temperature

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The COVID-19 disease, caused by the novel coronavirus, is the most serious health crisis since the Spanish flu of 1918, which is estimated to have killed between 50 million and 100 million people worldwide. By the latest count (March 29), the disease had spread to over 177 countries, with more than 630,000 cases reported and 30,000 recorded deaths. These numbers are increasing exponentially at present and the cases and deaths reported are both believed to be undercounted. Deaths are strongly concentrated in the older population (aged 65 and over) and among those with serious pre-existing conditions, according to a study by Chinese researchers (Liu et al, 2020) and extensive epidemiological data from South Korea and Italy.[1]

Although COVID-19 is now officially a pandemic, its spread across the world remains very uneven, with China reporting 59 cases per million, and Italy—the epicenter of the crisis at time of writing—over 1530 cases per million, while several countries with warmer climates, such as the Philippines, report fewer than 10 cases per million.

This uneven distribution has led to both fear and hope. Fear, because the disease might still spread virulently to Africa and other poor nations, where very few tests have been conducted and where medical systems are least equipped to cope. Hope, because the slower spread of the virus in hot climates might be an important signal that the disease will ease with the coming of spring and summer in the hardest-hit temperate zones. This has been the case with other strains of coronavirus in the past, such as those that are at the root of ordinary flu.

Though written in the 'fog of war', this note attempts to evaluate the importance of temperature in accounting for the spread of the virus. We attempt this despite the fact that reported cases are a very imperfect measure of the spread of the virus, mainly because of major differences in the frequency of tests. For example, based on the limited information available about testing, poor countries, which tend to be in warmer climates, test less and almost certainly tend to report fewer cases for that reason.

Still, after controlling for income and other factors that might influence the spread of the virus, our analysis suggests that temperature does play an important role in determining the extent of the spread. Our best guess, based on various regression specifications, is that a 1% increase in temperature from average levels (50 degrees Fahrenheit/10 degrees Celsius) could reduce the number of cases per million people by 0.5% (+/- 0.2%). We also find evidence that the incidence of disease is lower in very cold temperatures.

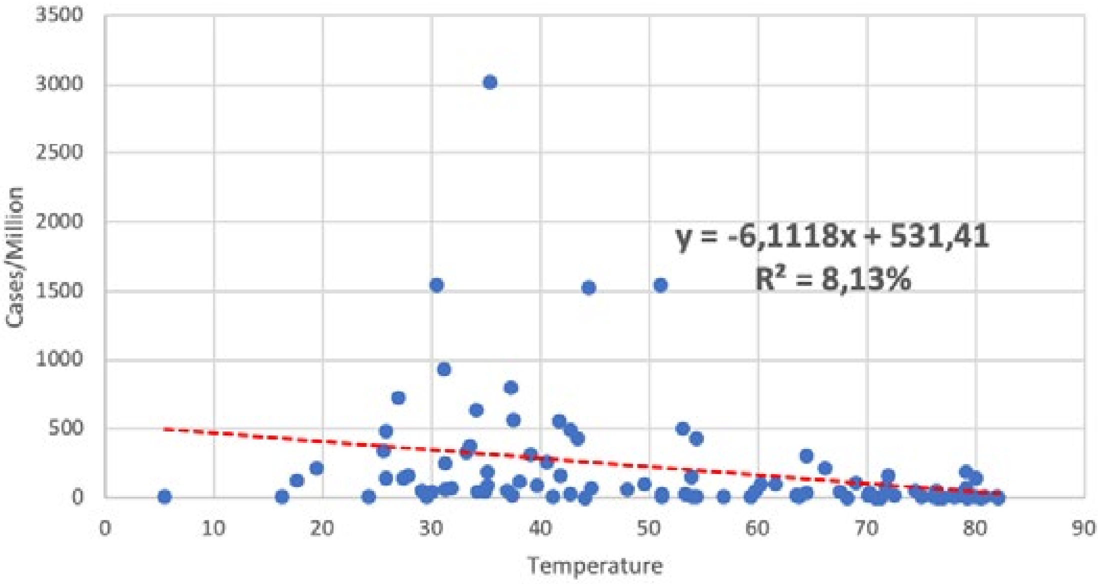
Our analysis is preliminary and needs to be confirmed by studies based on more complete data. Most needed are random tests of the population to ascertain the true rate of infections, which we expect, or rather hope, will become available in the near future. If confirmed, the policy implications of our results would be significant. In the final section, we briefly discuss what the policy implications might be.

1 For Italy, see https://lab.gedidigital.it/gedi-visual/2020/coronavirus-i-contagi-in-italia/

Spread of the Virus

To date, the main epicenters of COVID-19, the Hubei region of China, the Lombardy region of Italy, the city of Madrid, the city of New York, the town of Mashhad in Iran, and the city of Mulhouse in France, are all in temperate zones. Figure 1 shows that warmer regions appear to have been less affected.

Figure 1: Cases/million vs Temperature

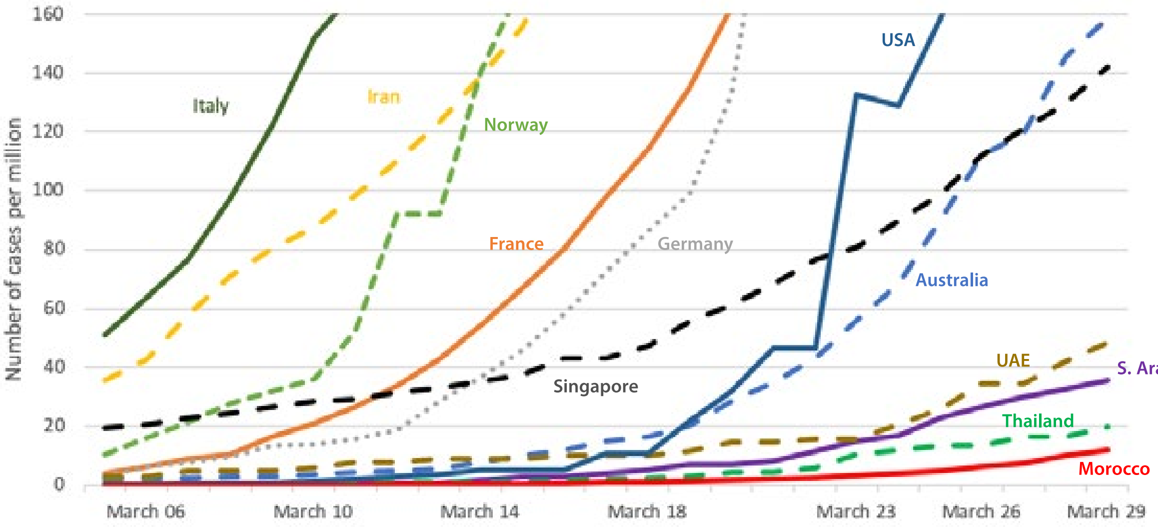


Source: WHO and Weatherbase.

For example, Italy's northern regions have been far harder hit than the warmer regions in the middle, while the regions in the south have been least hit.[2] A study by Chinese researchers, which has not been peer-reviewed, finds that the rate of contagion (R) in 100 Chinese cities was significantly affected by heat and humidity in the period prior to interventions by government to limit the spread, even after controlling for population density and GDP per capita as a proxy for medical preparedness (Wang et al, 2020). Applying ecological niche models, Araujo and Naimi (2020) estimated with 95% confidence that the interquartile temperature range for coronavirus infection is between 2 and 9.5 degrees Celsius. Bukhari and Jamil (2020) of MIT concluded that up to March 22, 90% of coronavirus transmissions had occurred within a temperature range of 3 to 17 degrees Celsius, and countries with warmer climates have seen less rapid transmission (Figure 2).

2 https://lab.gedidigital.it/gedi-visual/2020/coronavirus-i-contagi-in-italia/

Figure 2: Growth Curve of Number of Cases Per Million



Source: WHO. Note: The y-axis has been capped at 160 cases.

Similarly to influenza, the novel coronavirus might be inhibited from spreading by higher temperatures and increased humidity because droplets from coughs or sneezing travel less far, people spend more time outside in warmer climates, and they are less susceptible to being infected. Experts, however, remain divided on whether COVID-19 will follow this path, with many remaining agnostic or circumspect[3].

Incidence of Infection and Testing

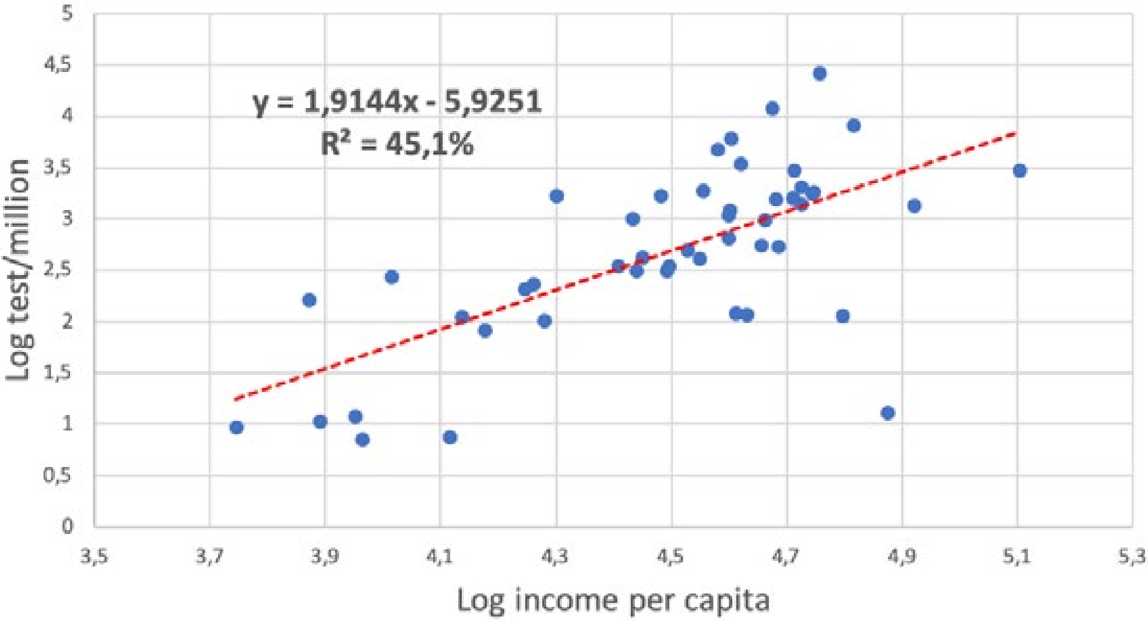
How should we measure the spread of the virus? Ideally, this would be done by testing the whole population and identifying positive cases. Tests are quite accurate but not perfect, with both false negatives and false positives[4]. However, testing capacity is severely limited at present and testing everyone is impossible in a single country of any size, let alone throughout the world. The next best would be to conduct tests on sufficiently large and representative random samples of the population of each country. To our knowledge no such random testing exercises has been attempted. Instead, in view of the cost and shortage of testing equipment (including testing kits, laboratory capacity, and protective equipment for those conducting the test), tests tend to be carried out only on selected individuals, nearly always those that already show advanced symptoms of the disease, including high fever and difficulty breathing, and those who have been directly exposed to it, including medical workers or close family and acquaintances of confirmed cases.
Table 1 shows the very large disparity in the frequency of tests in different countries, ranging from about 10,000/million in Bahrain and Norway, to 10 per million in Philippines and India. There is a statistically very weak negative relationship between the frequency of tests and the share of those found positive for the virus; less testing is weakly associated with a higher number of positive tests. Countries that are least capable or willing to test tend to reserve tests for those showing the most advanced symptoms. Nevertheless, countries that test more frequently tend to report more positive cases in

3 Such as Brittany Kmush, a public health expert at New York's Syracuse University, and David Cennimo, from Rutgers New Jersey Medical School.

4 https://www.medicinenet.com/script/main/art.asp?articlekey=228250.

absolute terms. As Figure 3 shows, there is a statistically significant positive relationship between frequency of testing and per-capita income.

Figure 3: Number of Tests/Million vs Income Per Capita



Source: European CDC and WDI data.

Poor countries tend to test far less than rich countries. But that is not always the case. For example, frequency of tests in the United States, the richest country in the sample, has been far less than in Slovenia or China.

Table 1: Number of Tests Per Million and Share of Positives by Country[5] (Data from March 20)[6]

	Number of tests/million	Share of positive tests
Iceland	25988.9	4.5%
Bahrain	11880.0	1.5%
Norway	8229.6	4.0%
South Korea	6132.7	2.8%
Slovenia	4769.3	2.9%
Italy	3423.5	22.7%
Qatar	3019.8	5.2%
Australia	3016.0	1.2%
Germany	2013.8	2.3%
Estonia	1895.7	11.3%
Denmark	1850.8	11.7%

5 Testing data was only available for 50 countries.

6 The most recent data, with sources indicated is available on the WorldinData site https://ourworldindata.org/coronavirus-testing-source-data.

Austria	1764.8	17.0%
Belarus	1686.8	0.2%
Latvia	1663.6	3.5%
Belgium	1607.4	8.1%
Canada	1571.0	1.5%
Sweden	1404.3	7.4%
Ireland	1359.8	3.4%
Israel	1222.9	2.8%
Czechia	1093.5	7.8%
Russia	993.4	0.1%
Iran	978.0	14.2%
United Kingdom	971.9	4.1%
Spain	642.1	37.3%
France	548.6	12.2%
Finland	543.7	12.0%
Palestine	498.6	1.5%
Slovakia	497.0	5.1%
Romania	425.4	3.7%
Lithuania	413.7	6.0%
Panama	348.3	4.7%
Poland	344.2	3.3%
Croatia	309.1	6.4%
Hungary	307.8	2.8%
Armenia	275.4	6.4%
China	229.8	24.1%
Costa Rica	207.8	4.8%
Vietnam	163.7	0.6%
New Zealand	119.5	1.9%
Japan	117.8	5.9%
United States	115.4	7.0%
South Africa	111.4	3.2%
Thailand	102.0	2.1%
Colombia	82.6	3.5%
Morocco	13.8	14.9%
United Arab Emirates	13.0	78.4%
Philippines	11.9	18.1%
India	10.7	1.3%
Pakistan	9.3	12.2%
Indonesia	7.6	18.2%
Ukraine	7.1	8.2%

Source: Worldometers.

The scarcity of tests also means that asymptomatic individuals who are carriers of the virus (and may also be infectious), and even some of those who are symptomatic but at a less-advanced stage of the disease, remain unidentified. How big might the group of asymptomatic infected individuals be? It is impossible to give a general answer, but one indication comes from the town of Vò in the Veneto region, an epicenter of the disease, where tests carried out in February covered the total population of 3300 people. The tests identified 3% of individuals as having COVID-19, about half of whom were asymptomatic. If this is any guide, in a context in which the epidemic is quite advanced and where tests are relatively frequent (as in Italy or Korea, for example), one should double the number of positive individuals to arrive at a more reliable figure of total infections. However, studies that use epidemiological models based on recent experience (such as with the Diamond Princess cruise ship[7]) suggest much higher rates of contagion and of asymptomatic or weakly symptomatic infected individuals (Mizomoto et al, 2020).

Although data on reported cases, drawn from the World Health Organization's Situation Report of March 29, is far from ideal to measure the real spread of the virus in the whole population, it most likely provides a fair representation of the prevalence of cases of people who are ill and whose symptoms are already advanced[8]. This is the part of the population that threatens to overwhelm the medical system and requires the most pressing attention.

Accounting for the Spread of the Virus

To identify the importance of temperature in affecting the spread of the virus, we need first to control for other factors. We hypothesize that (at least) five other factors are important: per-capita income, which affects the availability of tests and stands for various institutional and 'openness' factors; the intensity of people exchanges with China, the initial epicenter of the crisis; the demographic profile of the population, notably the share of older people who are most prone to become infected; the preparedness of the medical system to anticipate and prevent epidemics; and density of population. Other factors that might clearly play a role, such as humidity, are not considered here, in part because they vary greatly across national territories in even the smaller countries.

a. Bivariate Relationships

We discuss the effect of each factor briefly in turn, before turning to a multivariate analysis in the next section.

Temperature

As already shown, there is a strong presumption that temperature affects the spread of the virus. Table 2 shows the 95 countries in our sample sorted by temperature quintile[9],

7 On the Diamond Princess cruise ship, which reported over 700 positive cases and was held up in Okinawa, Japan, about a third of the positive cases were asymptomatic, according to press reports.

8 This may not be true in cases, such as Wuhan and Bergamo, where hospitals became overwhelmed and many patients with severe symptoms could not be admitted, and many, including the dead, were not tested or counted as victims of the virus.

9 Although the outbreak has reached more than 177 countries, we excluded countries with small populations (less than 1 million people) and also countries reporting very few contamination cases (less than 20 cases), from our analysis to avoid biasing the results with outliers. Many of the excluded countries are in Africa, and have warmer climates.

based on historical temperatures in January, February, and March. Countries in the second-coldest quintile[10], those in temperate zones, reported the largest number of cases, 400 per million inhabitants. Warmer quintiles have reported fewer cases, falling off to 30 cases per million in the warmest countries. However, very cold countries have reported significantly fewer cases than those in the second quartile, 280 per million. The standard deviation of cases/million within each quintile is very high, highlighting the importance of third factors.

Table 2: Reported Infections Per Million and Temperature

Temperature quintile	Mean of temperature per quintile (F.)	Mean of infections/ millions	Standard deviation of infections/million
5th	78.7	30.2	51.5
4th	67.4	71.3	80.0
3rd	50.1	287.0	476.6
2nd	37.2	404.1	673.5
1st	25.6	281.7	397.0

Source: WHO data.

The distribution by quintiles suggests that the effect of temperature on cases per million is not linear. This is also shown in Figure 1, which could be visually interpreted as bell-shaped. The conjecture that very cold temperatures (and very hot temperatures) reduce the propensity of the coronavirus to thrive and spread is also consistent with the temperature ranges reported in the previously cited studies by Wang et al (2020) and by Araujo and Naimi (2020). Both studies place the 'sweet spot' for propagation of the virus near 10°C/50°F.

Income Per Capita

Table 3 shows a positive relationship between reported cases and income quintiles. This might reflect frequency of testing, and a host of other factors. For example, richer countries tend to be more open, to receive more tourists, including Chinese tourists, and to have older populations than poorer countries. As with temperature, the standard deviation of cases/million within each income quintile is high.

Table 3: Reported Infections Per Million and Income Per Capita

Income per capita quintile	Mean of income per capita per quintile	Mean of infections/million	Standard deviation of infections/million
5th	68315.9	565.9	703.5
4th	38863.4	368.0	445.6
3rd	24266.9	85.6	101.0
2nd	14557.8	37.9	36.5
1st	6050.8	16.9	34.0

Source: WHO and WDI data.

10 Our temperature data source (http://www.weatherbase.com/), computes the averages using the temperatures by cities during several past years (from 20 to 90 years).

People exchanges with China

Data on Chinese visitors by country was not available to us. As a proxy, we used 2018 trade (exports plus imports) with China per capita. Here again, we found a quite strong increasing relationship, although not monotonically, of infections across quintiles. Infections are highest in countries where trade with China is on average $1300 per capita, and lowest where trade is 10 cents per capita.

Table 4: Reported Infections Per Million and Exchanges With China

Trade/population quintile	Mean of trade/ population per quintile	Mean of infections/ million	Standard deviation of infections/million
5th	4.4	326.1	371.7
4th	1.3	476.1	727.8
3rd	0.7	165.2	357.6
2nd	0.3	71.4	99.5
1st	0.1	35.4	63.7

Source: WHO, CNUCED and WDI data.

Demographic Profile

Older people tend to suffer worse from COVID-19, and the vast majority of fatalities are in this group (Liu et al, 2020). Countries with a high share of people over 65 tend to have more infections, but the relationship is not quite monotonic, and the standard deviations within quintiles are very large.

Table 5: Infections/Million Per Quintile of Population Over 65

Population aged over 65 quintile	Mean of population aged over 65 (%) per quintile	Mean of infections/ million	Standard deviation of infections/million
5th	20.8	421.2	437.5
4th	16.6	292.0	413.9
3rd	11.3	264.8	678.8
2nd	6.6	54.5	103.1
1st	3.1	79.3	79.3

Source: WHO and WDI data.

Medical Preparedness

An indicator of medical preparedness to anticipate and deal with epidemics is given by the Global Health Security Index (GHS index), provided by the WHO for 195 countries. The bilateral relationship between medical preparedness and infections is weak, with the most-prepared countries, according to the index, reporting the largest number of infections. This counterintuitive result might be due to various factors, including that the most-prepared countries tend to be the richer countries and those that carry out more tests.

Table 6: Infections/Million Per Quintile of Medical Preparedness Score

Medical preparedness score quintile	Mean of medical preparedness score per quintile	Mean of infections/ million	Standard deviation of infections/ million
5th	69.9	470.5	438.1
4th	56.9	255.5	395.4
3rd	49.0	85.6	102.6
2nd	42.0	232.3	678.3
1st	33.7	30.3	97.7

Source: WHO, GHS index and WDI data.

Population Density

There is also a positive relationship between population density and cases per million, but it is not monotonic and exhibits large standard deviations within quintiles.

Table 7: Infections/Million Per Quintile of Population Density (people per km2 of land area):

Pop density quintile	Mean of pop density per quintile	Mean of infections/ millions	Standard deviation of infections/million
5th	896.4	352.8	688.3
4th	146.7	279.4	474.5
3rd	93.6	196.2	389.5
2nd	60.3	106.0	152.4
1st	17.8	139.8	189.6

Source: WHO, and WDI data.

Multivariate Analysis

The bivariate analysis suggests that it is not just high temperature that retards transmission but also very low temperatures. Previous studies, cited above, also suggest that the 'sweet spot' for transmission lies somewhere near 50°F/ 10°C. That level also happens to be the average temperature in our sample of 95 countries, which excludes many small countries and countries that report very few cases – mainly African countries. Accordingly, in our multivariate analysis, we tested the effect of both temperature and the absolute deviation of temperature from the 'sweet spot' on cases of infection per million people. With all variables expressed in logarithms, we tested specifications with various combinations of the control variables. It turns out that, among the control variables, income per capita is the most significant, and also has the largest effect on cases per million. As Table 8 shows, income per capita is strongly positively correlated with other control variables, namely trade with China, population aged over 65, and medical preparedness, suggesting that it may be picking up their effects as well.

Table 8: Per-Capita Income Correlations With the Other Variables

	INCOMEPC	TEMPERAT	TRADEPOP	AGEDPOP	MEDICALPR	POPDENSIT
INCOMEPC	1	-0.26	0.67	0.32	0.47	0.31

Regression of cases per million on all the independent variables yields a low level of significance of all the variables except per-capita income and temperature.

Below we report on two 'preferred' regressions. Both include temperature as absolute deviation from 50°F, which results highly significant, and more significant than the level of temperature. The first regression includes all the control variables except population density, which was not significant, and also excludes per-capita income on account of collinearity. The second regression includes per-capita income as the sole control variable. The full regression results are in the Appendix.

The first regression:
Infections=-3,47-0,47*Temperature +0,39*Trade+1,83*Medprep+0,77*Agedpop

The second regression:
Infections= -11,17 -0,34*Temperature +1,60*Income PC

In the first regression, all variables are highly significant. The coefficient of temperature deviation from 50°F is -0.47, to be interpreted as follows: for a 1% increase (decrease) in temperature above (below) 50°F, the number of cases per million increases (decreases) by 0.47%. All other variables are of the expected sign except for medical preparedness which has a positive coefficient, perhaps because the more-prepared countries test more.

In the second regression, the coefficient on temperature deviation is similar to the first regression: -0.34 and highly significant. The effect of per-capita income on cases per million is extremely significant, with a 1% increase in income per capita associated with a 1.6% increase in cases per million.

These outcomes are little changed from regressions carried out a week ago and ten days ago, when global infections were less than half of what they were on March 29. Still, there remains plenty of doubt about the robustness and interpretation of these results, especially in the light of the strong association between per-capita income and greater frequency of testing, and the rapid evolution of the situation. As more testing capacity and test results become available in poorer and typically warmer countries, the accuracy of our estimates should improve. That said, the evidence that temperature plays a significant role is we believe quite strong.

Possible Policy Implications

The inadequacy of our measure of disease spread, the disparities in testing, and the newness and rapid evolution of the pandemic do not permit us to draw strong policy conclusions at this stage.

Even so, based on our evidence and on previous studies, we can say with some confidence that COVID-19 spreads less readily in warmer climates. COVID-19 also appears to spread less readily in very cold climates.

If our findings are confirmed by more complete data, the disease may turn out to be a less disruptive and costly epidemic in countries where the climate is warmer. The fact that the virus appears to spread less rapidly in warmer climates today does not automatically mean that there will be significant slowing of the disease in the temperate regions of the Northern hemisphere as the weather warms. Still, if our cross-section results could be extrapolated to the evolution of the disease over time, they would suggest that the summer months will bring relief in the Northern hemisphere, while countries in the Southern hemisphere, including those in Africa, Latin America and East Asia, might actually see increased numbers of infections.

For example, if our quantification can be applied in Italy, where the temperature is about 85°F in August, then cases per million will decline by 35%, all other things being equal. As things stand, extrapolations based on epidemiological models suggest that the number of new infections (the flow) in Italy is close to the peak and will decline very sharply over the next month or so, and that the total number of people infected (the stock) will decline to very low numbers by the summer.

Other factors included in the regression suggest that the epidemic will be less disruptive and costly in poorer countries, despite their low medical preparedness, than in richer countries. This is because, not only of their typically warmer climates, but also their relatively young populations, lower population density in most cases, and the relatively low intensity of their people exchanges with China, and with the rest of the world.

If, as we believe based on the results reported by us and others, COVID-19 also spreads less readily in very cold climates, the coming of summer might mean greater spread of infections in regions such as Scandinavia, Northern Russia and Canada.

If confirmed by more comprehensive studies, as more data becomes available and the epidemic evolves, our preliminary analysis suggests that the probability of containing the disease in the temperate regions that are currently most affected, is greater than is generally believed.

While every country needs to adopt strong measures to contain the spread of the disease, poor countries in warm climates might not need to adopt extreme measures, such as prolonged lockdowns, which would have a disastrous effect on economies ill-positioned to cope.

Morocco, for example, where the number of infections is still small, has average historical temperatures of 75°F in April and 82°F in May, far above the coronavirus ‘sweet spot’.

It is too soon to be sure, but, helped by warm weather, measures such as stopping travel from the most-affected zones, moderate social distancing, extensive testing and isolation of those infected and at high risk of infection, and isolation of older people that are most vulnerable, could be enough to avoid a spread of infections that overwhelms the medical system.

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Appendix: Preferred Regressions

The first regression:

Infections=**-3,47-0,47*Temperature +0,39*Trade+1,83*Medprep+0,77*Agedpop**

Dependent Variable: LOGINFECTIONS
Method: Least Squares
Date: 03/30/20 Time: 18:40
Sample: 1 95
Included observations: 95

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-3.474742	2.724827	-1.275216	0.2055
LOGDEVTEMP	-0.470201	0.165153	-2.847067	0.0055
LOGTRADE	0.399914	0.110240	3.627671	0.0005
LOGMEDPREP	1.837952	0.775543	2.369891	0.0199
LOGAGED	0.779706	0.247126	3.155100	0.0022
R-squared	0.518092	Mean dependent var	3.944345	
Adjusted R-squared	0.496674	S.D. dependent var	1.909240	
S.E. of regression	1.354519	Akaike info criterion	3.495967	
Sum squared resid	165.1251	Schwarz criterion	3.630381	
Log likelihood	-161.0584	Hannan-Quinn criter.	3.550280	
F-statistic	24.18940	Durbin-Watson stat	2.266505	
Prob(F-statistic)	0.000000			

The second regression:

Infections= **-11,17 -0,34*Temperature +1,60*Income PC**

Dependent Variable: LOGINFECTIONS

Method: Least Squares

Date: 03/30/20 Time: 18:42

Sample: 1 95

Included observations: 95

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-11.17638	1.461940	-7.644899	0.0000
LOGDEVTEMP	-0.346915	0.144184	-2.406062	0.0181
LOGINCOMEPC	1.605709	0.138326	11.60814	0.0000
R-squared	0.612047	Mean dependent var	3.944345	
Adjusted R-squared	0.603614	S.D. dependent var	1.909240	
S.E. of regression	1.202043	Akaike info criterion	3.236991	
Sum squared resid	132.9314	Schwarz criterion	3.317640	
Log likelihood	-150.7571	Hannan-Quinn criter.	3.269579	
F-statistic	72.57116	Durbin-Watson stat	2.267647	
Prob(F-statistic)	0.000000			

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Uri Dadush is a Senior Fellow at the Policy Center for the New South, previously known as OCP Policy Center in Rabat, Morocco and a non-resident scholar at Bruegel. He is based in Washington, DC, and is Principal of Economic Policy International, LLC, providing consulting services to the World Bank and to other international organizations as well as corporations. He teaches courses on globalization and on international trade policy at the OCP Policy School and at the School of Public Policy at the University of Maryland. He was previously Director of the International Economics Program at Carnegie and, at the World Bank, Director of the International Trade, Economic Policy, and Development Prospects Departments. In the private sector, where he was President of the Economist Intelligence Unit, Group Vice President of Data Resources, Inc., and a consultant with Mc Kinsey and Co.

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About Policy Center for the New South

Policy Center for the New South, formerly OCP Policy Center, is a Moroccan policy-oriented think tank based in Rabat, Morocco, striving to promote knowledge sharing and to contribute to an enriched reflection on key economic and international relations issues. By offering a southern perspective on major regional and global strategic challenges facing developing and emerging countries, the Policy Center for the New South aims to provide a meaningful policy-making contribution through its four research programs: Agriculture, Environment and Food Security, Economic and Social Development, Commodity Economics and Finance, Geopolitics and International Relations.

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