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CORONAVIRUS AND CLIMATE: LEARNING FROM FRANCE

By Oumayma Bourhriba & Uri Dadush

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Coronavirus and Climate: Learning from France

O. Bourhriba & U. Dadush[1]

Policymakers across the world face a dilemma: to lockdown the economy, and see output and employment collapse, or to open and face a surge of COVID-19 infections and deaths that could overwhelm the medical system? The choice is especially stark in poor countries, where many depend on what they earn day to day, and where the medical system is entirely unequipped to deal with the virus. In this brief we assess the likely path and geographic spread of the epidemic. We do so by examining the effect of temperature and humidity on COVID-19 hospitalizations in 96 departments in Metropolitan France. The choice of France is based on the availability, quality, and uniformity of the required data. Our analysis suggests that high temperature and high relative humidity tend to impede the spread of the virus, while population density tends to facilitate its transmission. This does not mean that warmer weather is enough to contain the disease. However, we believe it is likely that warmer weather will slow the disease in the Northern hemisphere in the coming months, and that some countries in the tropical and near-tropical zones will be able to contain the disease by adopting social distancing and contact tracking, without being forced into prolonged lockdowns.

We approach the question of how climate affects the spread of COVID-19 with some hesitation, since we are economists, not virologists. Yet, viewed from the perspective of economic policy, the fact that all major epicenters of COVID-19, from Wuhan to Tehran, Bergamo, Mulhouse, Madrid and New York, are found in the temperate zone, is of great relevance, since—other things being equal—it is these regions that are likely to suffer the most fatalities and the greatest economic damage.

We note that past flu epidemics, many caused by viruses that are of the coronavirus species, have exhibited a pronounced seasonal pattern. As summarized in a widely-cited Journal of Virology article: “Experimental studies in guinea pigs demonstrated that influenza virus transmission is strongly modulated by temperature and humidity. A number of epidemiological studies have followed up on these findings and revealed robust associations between influenza incidence in temperate regions and local conditions of humidity and temperature, offering a long-awaited explanation for the wintertime seasonality of influenza in these locales” (Lowen and Steel, 2014).

In the three months since the scientific community became aware of COVID-19, several studies using a range of techniques have shown that the virus spreads more rapidly in temperate climates. These studies are preliminary and have not been peer-reviewed. One of the earliest studies—which was updated on April 12—examined the spread of COVID-19 across China and concluded that the rate of transmission of the disease was associated negatively with temperature and humidity after controlling for factors including density and per-capita income (Wang et al, 2020). Applying ecological niche

1. We thank Mahmoud Arbouch, Christophe Chamley, Jean Donsimoni, Philippe Schwarz, Robert Treitel for useful comments.

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, 2020, 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. Other studies reached similar conclusions (Ficetola and Rubolini, 2020; Liu and Zhi, 2020; Triplett, 2020). In a companion piece to this brief, Arbouch and Dadush (2020) found a highly significant association between temperature and the incidence of COVID-19 (positive cases per million population), across a sample of about 100 countries, after controlling for age structure of populations and intensity of exchanges with China, among other variables. It should be emphasized that none of the studies we reviewed claim that high temperatures and humidity are enough to extinguish the epidemic. The spread of COVID-19 is presently taking place in a wide range of climates, including in regions such as coastal Ecuador and Southern India, where temperatures and humidity are high.

Despite the consistency of findings by researchers from diverse institutions, and the fact that countries in the tropical and near-tropical zones have so far been spared the worst of the disease (cases scaled by population in hot climates are a fraction of those in temperate climates), many informed observers remain unconvinced by the notion that the novel coronavirus spreads less easily in warm weather. In some respects, the skepticism is justified[2]. Not only is the epidemic a recent occurrence, but the infection data on which the studies are based is highly suspect. Because of the lack of testing resources, typically only the worst symptomatic patients are tested, and many who contract the disease are asymptomatic and not tested. Studies have shown that as many as 10 times more people are infected in major epicenters of the disease, such as New York, than are counted. In contrast, outside the epicenters,that ratio is much lower[3]. The scarcity of testing resources is a global problem, but is especially acute in developing countries, which tend to have warmer climates and where testing capacity is even scarcer[4].

Frequency of testing is found to be strongly associated with countries' per-capita income, adjusted for purchasing power parity (PPP). This suggests that per-capita income can be used as a proxy (instrument) for frequency of testing[5]. In fact, when cases per million are regressed against temperature and PPP per-capita income, both the income and temperature variables results are highly significant in a large sample of advanced and developing countries (Arbouch and Dadush, 2020).

In this brief, we avoid altogether the many problems associated with measuring the spread of the disease, by focusing on COVID-19 hospitalizations. Hospitalizations provide only a partial picture of the disease, of course, but they do include only (though by no means all[6]), the most serious cases, which are those that threaten to overwhelm

2. The debate is well summarized in an article in the Business Standard, an Indian newspaper: https://www.business-standard.com/article/current-affairs/will-heat-humidity-slow-down-coronavirus-outbreak-what-experts-say-120032800510_1.html.

3. See https://www.bloomberg.com/opinion/articles/2020-04-15/covid-19-studies-imply-more-than-1-million-new-yorkers-with-virus.

4. For example, COVID-19 associated deaths in Jakarta and Istanbul appear to be vastly undercounted: https://www.nytimes.com/interactive/2020/04/21/world/coronavirus-missing deaths.html.

5. Using testing frequency as a right-hand-side variable in the regression to account for cases per million is not appropriate because testing frequency is partly determined by the spread of the disease.

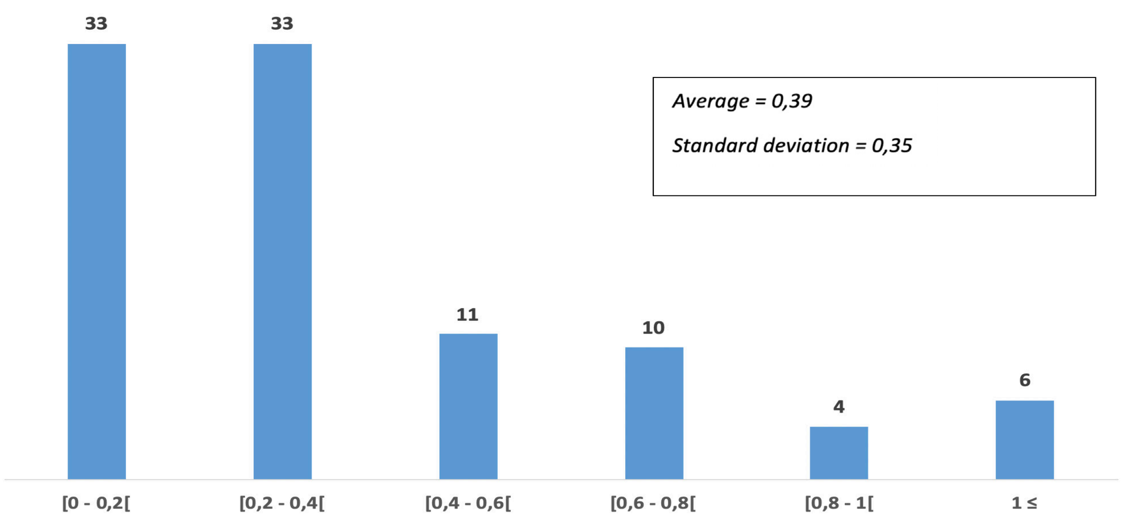
6. Tragically many victims never reach hospitals. In France, many of those who die without reaching hospitals become infected in nursing homes. See https://www.nytimes.com/interactive/2020/04/21/world/coronavirus-missing-deaths.html.

the medical system. In France, hospitalizations have been accurately measured and reported daily since March 18. France has excellent statistical capacity and a relatively homogenous single-payer medical system with uniform protocols. Lockdown and social distancing measures, which vary greatly across the world, and across provinces or states in large countries including China and the United States, are applied quite uniformly across the national territory in France. A possible disadvantage of focusing on French data is that the variation in weather across most departments (i.e. excluding the overseas departments) is far less than across the world. In France, the range during the relevant period was 5 to 13 degrees Celsius and from 61% to 86% relative humidity. By contrast, in cross-country analyses, the difference in February temperature between, for example, Stockholm and Abidjan is 34 degrees C. As it turns out, temperature and humidity appear to play a significant role in determining COVID-19 hospitalization, even in a territory the size of France.

Determinants of COVID-19 Hospitalization

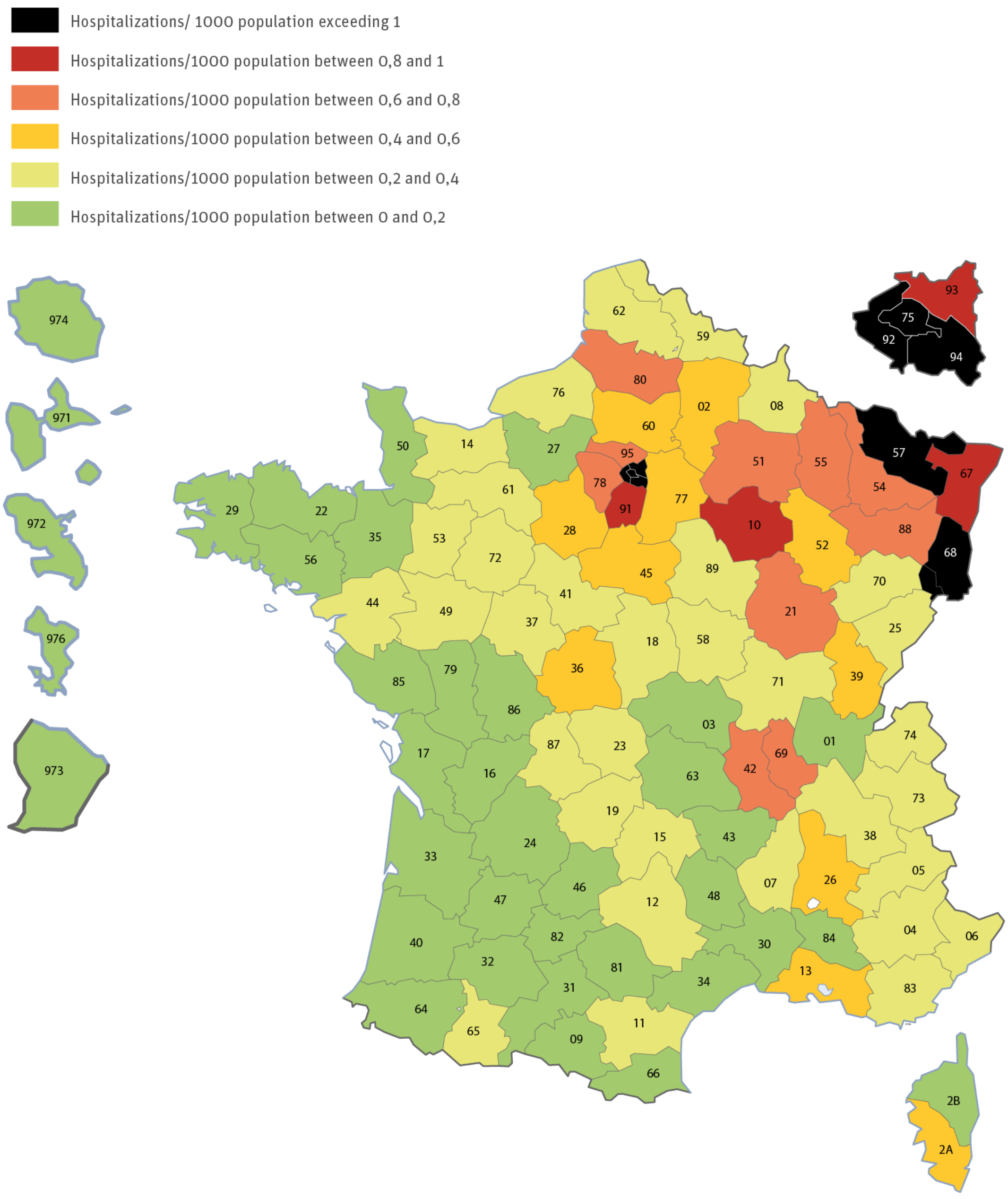
The variance in rates of COVID-19 hospitalizations in France is quite remarkable, ranging from close to 0.1 persons per thousand in the least affected departments to near 1.6 persons per thousand in the most affected departments, such as Paris (Figure 1 & 2; data as of April 13).

Figure 1: Distribution of Departments by Hospitalization per 1000 Capita



Note: The horizontal axis shows number of hospitalizations per 1000 populations in a range. The bars show the number of departments falling in that range.

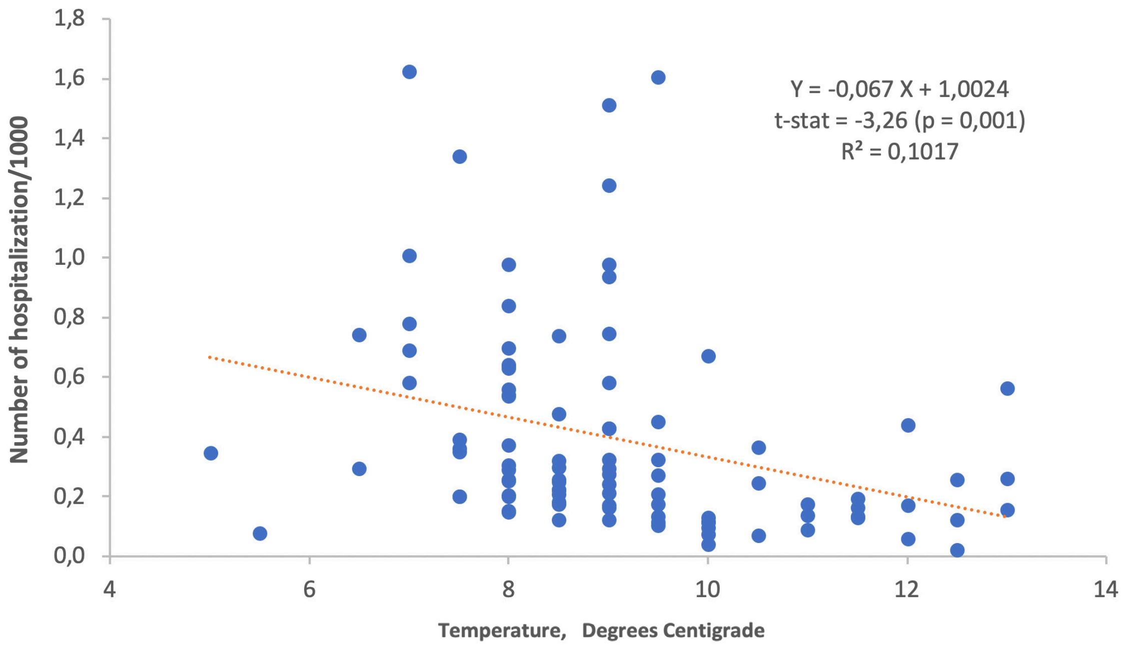
Figure 2: Distribution of French Departments by Hospitalization per 1000 Capita



What accounts for this variation? To identify the effect of temperature and humidity on hospitalizations we need to control for other variables. We can think of the following list of possible systematic influences on the incidence of COVID-19 hospitalization: population density, age structure of the population, tourist visits, and per-capita income. The latter may be a proxy for many possible influences, including medical preparedness, and interactions with the rest of the country and the world. Also, the date the epidemic reaches a critical threshold is likely important, since the epidemic can grow exponentially, and even a few days can make a big difference on infections and hospitalization[7]. We begin by reviewing the salient connections between the variables.

As can be seen from Figures 3 and 4 there is a significant negative relationship between temperature and hospitalizations per 1000 population and a somewhat less significant negative relationship with relative humidity[8]. The highest incidence of hospitalizations is in the 9-10 degrees C. range, consistent with the idea that the virus thrives in a 'sweet spot' near that range, as put forward by some of the studies we have referred to. In those modal cases, the relative humidity range is 70-75%.

Figure 3: Hospitalization per 1000 Population vs Temperature

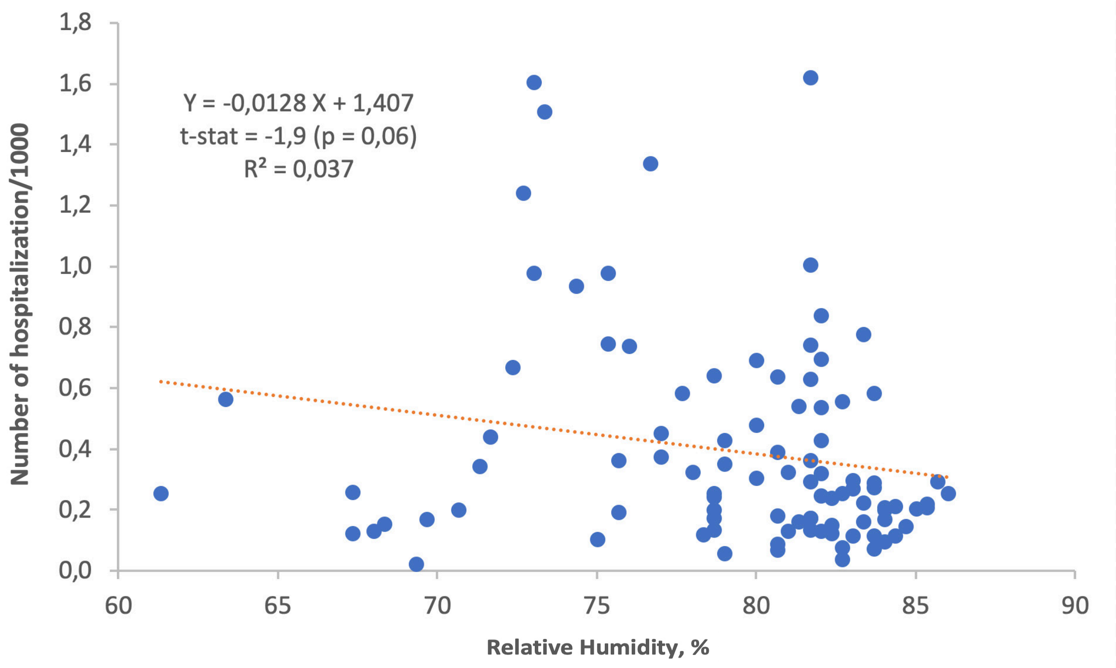


Note: each dot represents a department

7. Note that departments that crossed the thresholds more recently may benefit from rising temperature, creating a potential collinearity problem in regression

8. The source of the data is World Weather online

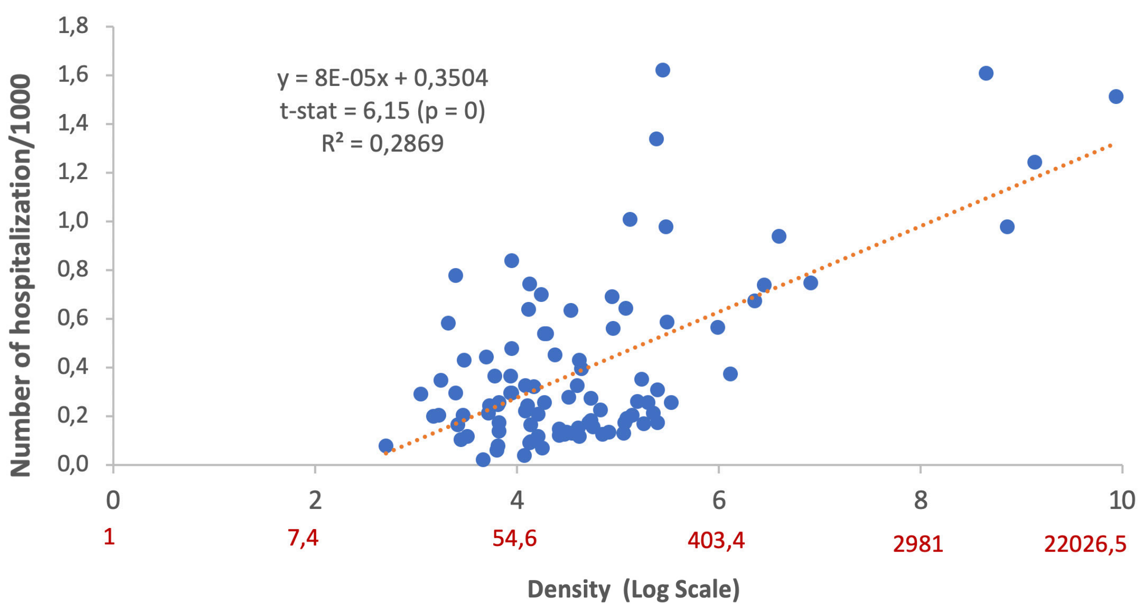
Figure 4: Hospitalization per 1000 Population vs Humidity



Note:each dot represents a department

As Figure 5 shows, population density is strongly associated with increased incidence of hospitalization. Of the eight departments where the incidence of hospitalization is equal to or greater than 1 per thousand, four (Paris, Hauts-de-Seine, Seine-St-Denis, and Val-de-Marne) have more than 5000 inhabitants/square kilometers. Three others (Alpes-de-Haute-Provence, Creuse, and Lozère) have very low density, underscoring the importance of other factors.

Figure 5: Hospitalization per 1000 Population vs Density[9]

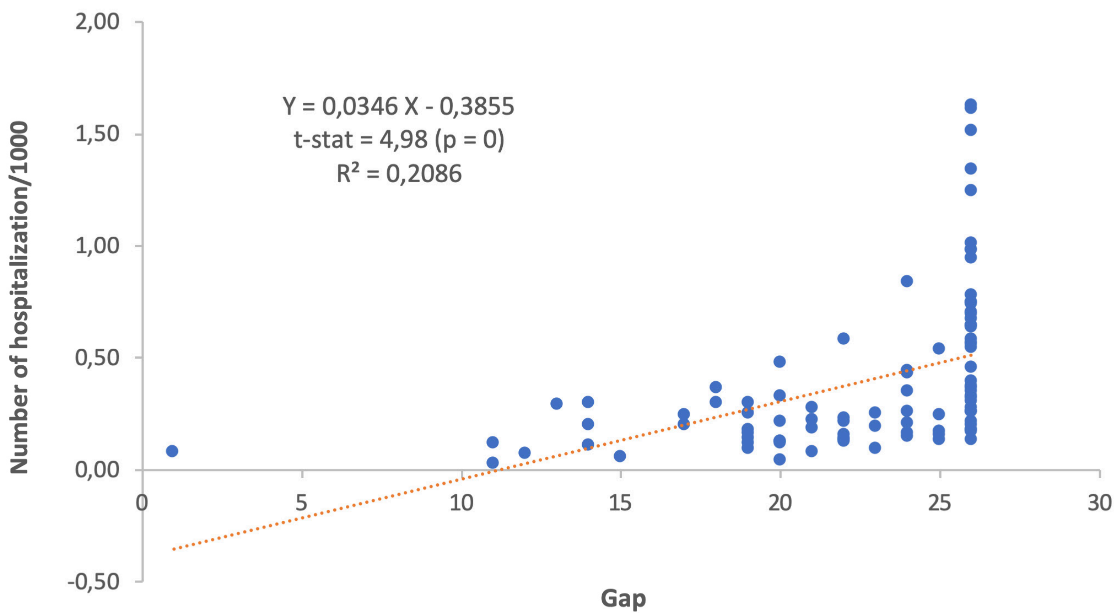


Note: Density is defined as population/square kilometer. Each dot represents a department

9. The red numbers below the X axis represent the anti-log values of density.

The timing of the epidemic clearly matters, too. Unfortunately, the hospitalization data is only available since March 18, by which time 40 departments had already more than 10 hospitalizations, which we use arbitrarily as the threshold for the epidemic entering a critical phase. Even so, we observe a strong positive relationship between the number of hospitalizations and the number of days since the threshold was crossed, which we refer to as 'Gap'.

Figure 6: Hospitalization per 1000 Population vs Gap



Note: "Gap" refers to the number of days to April 13 since the threshold of 10 hospitalization/1000 was reached. Each dot represents a department.

In contrast to the cross-country study by Arbouch and Dadush (2020), the relationship between per-capita income and hospitalizations is not found to be significant, and it is not shown here. The variation in incomes across French departments is small relative to that across the world, and the quality of institutions—for which income can be a proxy—is relatively homogenous. Also not shown is the relationship between share of the population over 65 in each department and hospitalizations. Many hospitalized patients in France are younger than 65 and the age variable turns out to be not significant. The relationship between tourist arrivals (measured the number of visitors to collective tourist accommodation) and hospitalization is also found to be not significant and is not shown.

Some relationships between the independent variables should also be highlighted. The correlation matrix including the variables found to be significant is featured in Table 1, with all variables expressed in logarithms. Note that the Gap variable is strongly positively correlated with density, indicating that the epidemic spread first to the departments with the highest population density. But the Gap variable is only very weakly correlated with temperature and humidity, indicating that the epidemic was, from the start, widely spread across the national territory. Also note the strong negative correlation between temperature and relative humidity, creating a collinearity complication in regressions, which we come back to below.

Table 1: Correlation Matrix

	Hospitalization	Density	Humidity	Temperature	Gap
Hospitalization	1				

Density	0,514***	1			
	(0,000)	-----			
Humidity	-0,198*	0,496***	1		
	(0,0528)	(0,000)	-----		
Temperature	-0,399***	0,142	-0,460***	1	
	(0,0001)	(0,167)	(0,000)	-----	
Gap	0,440***	0,396***	-0,193*	0,147	1
	(0,000)	(0,0001)	(0,060)	(0,152)	-----

Notes:The correlation ranges from ‘0” (no discernible co-variation) to “1” (identical co-variation). The probabilities of t-statistic are in parentheses, denoting significance of the relationship. Significance at the 1%, 5%, and 10% levels indicated by ***, **, and *, respectively.

Considering the speed at which COVID-19 is spreading, it is also important to verify that the relationships we observe are stable, i.e. that the relationships are robust to changing dates. More specifically, we need to check whether lower hospitalization incidence in some departments is a purely temporary phenomenon, as the epidemic in those departments is still at an early stage. We found only a very weak positive relationship between growth rates of hospitalization and the level of hospitalization, and between the growth of hospitalization and the length of time since the epidemic crossed the threshold.

Figure 7: Growth Rate of Hospitalization vs Gap

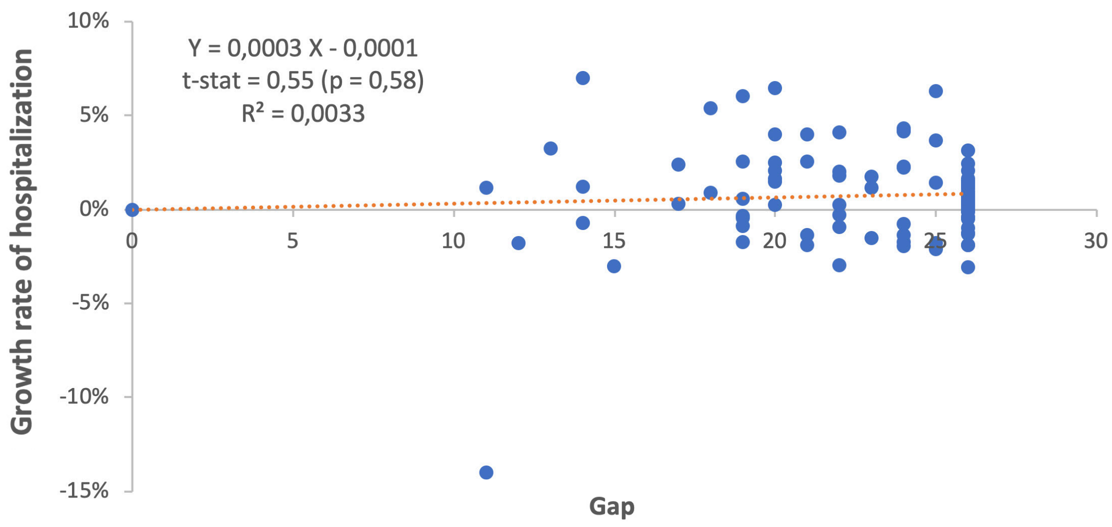


Figure 7 shows the latter relationship, suggesting that the relationships we observe are quite stable over time.

Multivariate Analysis

We regressed hospitalizations/1000 people against all the variables identified above, all in logarithms. The robustness of the relationships we observed is confirmed by the OLS regressions, which yield very similar results using data from April 1, 6, 9, and 13. Note that from April 1 to 13, the number of hospitalizations in France increased very rapidly from 24,543 to 31,952, or a little over 2% a day.

Table 2 reports two sets of regressions carried out on the April 13 data. The first regression omits variables that were found to be non-significant (age structure, per-capita income, tourists) and also omits the Gap variable, denoting the number of days elapsed since the threshold of 10 hospitalizations was crossed, which we include only in the second regression.

The first regression captures about half the variation in hospitalizations across departments, and identifies temperature and density as strongly significant and of the expected sign, with relative humidity also of the expected sign and significant at over the 90% level. When we drop the humidity variable, which is strongly negatively correlated/collinear with temperature (Table 1), the explanatory power of the regression remains almost unchanged, and the coefficient on temperature is a shade higher.

The second regression includes the Gap variable, which turns out to be highly significant. Including the Gap variable also significantly improves both the explanatory power of the regression and the significance of the temperature and humidity variables. This confirms to us that the observed lower rate of hospitalizations in the warmer regions of France is not mainly because the epidemic is still young, but likely reflects lower transmission rates of COVID-19.

Table 2: OLS Estimates of the Effects of Density, Humidity, Temperature, and 'Gap' on Hospitalization

	Regression (1)	Regression (2)
C	13,898*** (5,188)	13,556*** (4,635)
Density	0,326*** (0,056)	0,230*** (0,053)
Temperature	-2,634*** (0,377)	-2,826*** (0,339)
Humidity	-2,508** (1,064)	-2,773*** (0,952)
Gap		0,768*** (0.156)
Adjusted R^2	0,506	0,605

Notes: No. of observations is 96. The variables are expressed in log. Standard errors are reported in parentheses. Significance at the 1%, 5%, and 10% levels indicated by ***, **, and *, respectively.

To examine the robustness of these regressions, we carried out the exercise for four different dates, as already mentioned. We also omitted from the sample the five departments with the highest incidences of hospitalization, which may have run out of hospital beds. We also, separately, omitted the five departments with the lowest numbers of hospitalizations, where hospital beds might have been abundant, and patients might have been admitted more easily. We also ran the regressions omitting both sets of outliers. In all these instances, we obtained similar results. As an additional robustness check, we added to the sample five French Overseas Departments, which are all in tropical zones and where institutions, incomes, and other factors differ from Metropolitan France. We found that the explanatory power of the regression was reduced, but the significance of all the independent variables remained very high. The Gap variable, however, ceased being significant.

We also carried out a check on robustness of our conclusions using an entirely different data set. In an effort to obtain a more accurate picture of mortality due to Covid-19, INSEE has just published data on “excess deaths”[10] in France by department over March 1st to April 6th. The data show that many departments had no excess deaths, whereas departments at the center of the epidemic report deaths that are double or more those of last year. We would expect that if temperature, humidity and density affect the spread of the epidemic as measured by the incidence of hospitalization, they also cause excess deaths. This was confirmed in the regression below (Table 3) which suggests that a 1% increase in temperature is associated with a 0.6% reduction in excess deaths. Density is highly significant in the regression, while humidity is only weakly significant[11].

Table 3: OLS Estimates the Effects of Density, Humidity and Temperature on Excess deaths

	Excess deaths
C	3.219** (1.705)
Density	0.139*** (0.018)
Temperature	-0.606*** (0.349)
Humidity	-0.546 (0.349)
Adjusted R^2	0.518

Notes: The independent variables are expressed in log. Standard errors are reported in parentheses. Significance at the 1%, 5%, and 10% levels indicated by ***, **, and *, respectively.

The regressions suggest a significant effect of temperature and humidity on hospitalizations. Thus, a 1% increase in temperature may be associated with a 2.8% reduction in hospitalization (+/-0.35%). If this relationship were to hold over time, as

10. It is defined as change in cumulative deaths from 1 March to 6 April 2020 compared to cumulative deaths from 1 March to 6 April 2019 by department.

11. Other variables we tested turned out to be non-significant, including tourism, income and – surprisingly – population over 65.

well as cross-sectionally, it would imply a vast decline in the spread of the disease over the summer months. Note, however, that the variation of temperature in the sample is only between 5 and 13 degrees C., and the July/August temperature in Paris—a major epicenter of the disease—is on average 25 degrees C., well outside the in-sample range. This, and the fact that the regression anyway accounts only for about half the variation of hospitalizations across departments, raises a note of caution against firm predictions. Although temperature is clearly significant, many factors other than temperature affect the incidence of hospitalization.

So, our analysis, while suggestive, provides only a partial explanation for the spread of COVID-19 in France, and does not permit the drawing of strong conclusions. It is evident from numerous anecdotes, for example, that the epidemic was made far more severe in certain locations by random occurrences, such as popular football matches, religious gatherings, festivities, and celebrations involving large numbers of people. We may also be missing some systematic influences that are correlated with temperature, or measuring imperfectly those variables that have been included.

Policy Implications

We have presented evidence that temperature and humidity might have a significant effect on COVID-19 hospitalization, even in a relatively small geography such as France, where the variation in weather is limited compared to that across countries at different latitudes. This finding corroborates those of previous studies carried out on data on reported infections which—we believe—provides a less-accurate picture of the spread of the epidemic than hospitalizations. The effect of density is also shown to be important. Our results appear to be robust over time, i.e. they are not a reflection principally of the ‘age’ of the epidemic, and are robust to changes to the composition of the sample of departments. The French case might thus provide a clue to why the spread of COVID-19 has been limited in Africa, where the weather is warmer and where countries are less-densely populated.

The French case could also help explain the remarkable similarity in the reduction in the growth of infections noted in recent weeks in countries in the Northern hemisphere with very different approaches to social distancing, such as Sweden, which has implemented few such measures, and Italy, where the lockdown is complete (Ben Israel, 2020)[12]. It is possible that warmer weather might already be slowing the spread of the virus, and that this effect is additional to those from social distancing.

A tentative policy implication from these findings is that it is more likely than generally understood that lockdowns can be relaxed successfully and increasingly as the summer approaches. Moreover, policymakers may have more freedom in terms of how they approach de-confinement—i.e. how much social distancing, testing, travel bans are needed—than is generally believed. However, our findings would also suggest that authorities are correct in fearing a possible resurgence of the virus in the winter, and that they are correct in strengthening their medical capacity to prepare and in their large investment in finding a vaccine . Improved medical capacity would be especially important in regions where the climate is colder and drier.

12. https://drive.google.com/file/d/1rkM9Yl-ZviHAHUblcMv3w7vQSmDw7EXC/view

While all countries need to take precautions and preventive measures, some countries in the tropical and near tropical zones might find that the adoption of extreme lockdown measures can be avoided or put in place only for a short period. In countries in the tropics where hospitalizations are contained and where hospital capacity is available, social-distancing measures, combined with suppression measures (testing and tracing), might turn out to be enough to contain the epidemic. We certainly would not claim that warmer and more humid weather is enough to keep the novel coronavirus at bay, but we suspect that it will help.

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Appendix: Data Definitions and Source

Variable	Description	Data source
Hospitalization	Number of people cur-rently hospitalized per 1000 population	Hospitalization: Open platform for French public data of National health Agency "Santé Publique France" Population per department: INSEE
Density	Population per square kilometer	INSEE
Humidity	February and March average of relative hu-midity in percentage	World Weather online
Temperature	°C average of February and March	World Weather Online
Per capita In-come	Disposable Income per Consumption Unit	INSEE
Aged popula-tion	Population ages 65 and above	INSEE
Tourists	Hotels and other short-stay accommodation nights	INSEE

About the author, Uri Dadush

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 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.

About the author, Oumayma Bourhriba

Oumayma Bourhriba is a Research Assistant in Economics at the Policy Center for the New South. Her research areas cover macroeconomics and long term economic growth. She is currently working on themes related to Foreign Direct Investments in Morocco and infrastructure development in Africa. Previously, she worked on international trade issues. Oumayma holds a master's degree in applied economics, and is currently a PhD student at Mohammed V University in Rabat. She joined the Policy Center for the New South in September 2019.

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Policy Center for the New South

Suncity Complex, Building C, Av. Addolb, Albortokal Street,
Hay Riad, Rabat, Maroc.
Email : contact@policycenter.ma
Phone : +212 (0) 537 54 04 04 / Fax : +212 (0) 537 71 31 54
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