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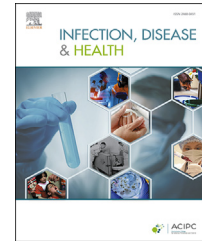
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Research paper

Understanding Covid-19 transmission: The effect of temperature and health behavior on transmission rates

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Abstract *Background:* Covid-19 pandemic is an uncharted territory for the world's population. Countries are seeing measures they would have never considered under democratic governance in an attempt to contain case numbers. The role of outside air temperatures have been implicated as a potential factor involved in disease transmission. However, to this date, there has been no clear evidence to suggest either way. Along with temperatures, infection control and protection measures as well as how well people adopt these measures are likely to play a role in disease transmission and case growth rates seen across countries.

Methods: The current study uses panel data estimation for the original EU-15 countries in an attempt to explain the role of outside air temperatures, health behavior and government-imposed containment measures on Covid-19 transmission rates.

Results: The preliminary evidence suggests that containment measures are highly effective in slowing down the spread of Covid-19. Years of education also appears to have a small but negative association with disease transmission rates suggesting that populations with higher educational attainments may be doing a better job of self-protection. Temperature appears to have a very small, but statistically significant impact on the viral transmission rate where a 1 °C increase in temperatures is estimated to reduce Covid-19 transmission by 0.9 percent.

Conclusion: Results are robust and clear. Temperature plays a small but significant role on Covid-19 transmission rates. However, it is quite possible that we may not have yet reached temperatures which may exert more pronounced effects on viral activity. Further research is warranted when more data becomes available, especially covering the months of July and August.

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Highlights

- Air temperatures appear to have a small but statistically significant negative association with Covid-19 transmission rates.
- According to panel data estimates, 1 °C increase in temperature can result in a 0.9 percent decrease in Covid-19 transmission.
- Education, used as a proxy of health behavior, has a strong negative association with Covid-19 transmission rates.
- Early government response has a highly significant effect in reducing viral transmission among the population.

Introduction

Coronaviruses periodically make headlines with deadly strains like the SARS-CoV, MERS-CoV and finally, SARS-CoV-2. Since the first identified case in December 2019 in the city of Wuhan in China, SARS-CoV-2 has spread globally, resulting in hundreds of thousands of deaths worldwide from a condition it causes known as CoVid-19. As of mid-March, the total number of cases in China had been surpassed by the number of cases in the rest of the world [1]. The World Health Organization (WHO) has classified the disease a pandemic with over 210,000 active cases and more than 8,000 deaths worldwide as of March 11, 2020 [2]. With more countries reaching triple and quadruple digits of active cases, lockdowns and state of emergency declarations have been a common practice worldwide.

While individual countries are taking their own measures in an attempt to slow down or contain the viral spread, the severity of measures are quite asymmetrical across the globe. China, as the origin of the pandemic, has successfully reduced the incidence of new cases through the employment of highest level of national response management protocols [3]. Although less aggressive, Singapore, Taiwan and Hong Kong also appeared to have their case numbers in control in the early phases of the viral spread through early implementation of travel restrictions, social isolation and quarantine measures [4]. However, those countries following more relaxed strategies initially only to experience exponential case explosions had to resort to lockdown and state of emergency measures to slow down the spread as in the cases of Italy, Spain, France and many more to follow afterwards [5]. With more cases being reported and the death toll rising, governments are trying to find a balance between prioritizing measures to reduce mortality and keeping an acceptable level of economic activity. In the meanwhile, experts are continuously trying to observe virus characteristics and behavior that might shed light on its transmission, spread and possible protective measures.

The relationship between viral infections and meteorological conditions has been of interest in the past as an attempt to better understand virus behavior. It has been proposed that warmer climates can possibly slow down the spread of viral infections. The SARS-COV strain of the virus was observed to survive longer on surfaces at lower temperatures and low relative humidities [6]. The recent MERS-CoV endemic in the Middle East was observed to have a

negative relationship between temperature and case incidences in a case-crossover analysis. Authors also reported a positive association with humidity [7]. Another study focusing on the SARS-CoV strain found a statistically significant difference between viral inactivation using four, twenty and forty-degree Celsius experiments. The virus had longest survival on metal surfaces at four degrees and shortest survival at forty degrees, suggesting a role of temperature on viral spread. Another study on SARS-CoV finds that the daily incidence of cases during the endemic was 18-fold in lower temperatures compared to higher temperatures [8].

Nevertheless, we observe rising case numbers and death tolls in countries with warmer climates as well, therefore, the precise role of temperature in Covid-19 transmission still remains a question unanswered. The WHO has suggested that while there is currently no evidence at hand regarding the role of weather on the current pandemic, it is an area worth investigating [9].

A study by Ref. [10] investigates a total of 26 countries with reported SARS-CoV-2 positive cases and find no significant relationship between the spread of virus and temperature. However, the study covers quite a brief timeline with a narrow range of temperature variability (6.70 and 12.42 °C). Another study focuses solely on China and finds a statistically significant impact of temperature on case doubling times. Authors find that a 20-degree Celsius increase in temperature is likely to slow down doubling time by 1.8 days [11]. Besides viral survival, cold exposure is also implicated to play a crucial role in human immunity. Cold temperatures are associated with a reduced blood supply to the nasal mucosa, which, in turn, reduces the provision of immune cells to this port of entry into the lungs, making people more susceptible to microbial infections in wintertime [12]. Moreover, people are more likely to spend more time in confined spaces in winter, possibly contributing to faster transmission of microorganisms between hosts.

Besides temperature and environmental conditions, protective measures play a significant role in spread of viral diseases. Given that the current virus is spread through saliva, droplets and contact with contaminated surfaces, the more careful people are with infection protection and control measures, the lower the incidence of new cases. It is often argued that years of schooling and educational attainments are directly related to health behavior [13]. show a dose–response relationship between years of

schooling and healthy and unhealthy habits. Building on this, one might argue that countries with higher average years of schooling should do a better job slowing down the spread of the virus by making more informed decisions about infection protection practices.

In this study, the rate of spread of SARS-CoV-2 is being considered as a function of outside air temperature as an environmental factor and years of schooling as a behavioral component. We test the hypothesis that warmer climates and increased years of schooling are possible factors that can slow down the spread of the SARS-CoV-2 pandemic. The rest of the paper is organized as follows: Section [Methodology](#) introduces the data and the model used in this study while results are discussed in section [Results and discussion](#). This is followed by a brief conclusion in section [Conclusion](#).

Methods

Data and Variables

This study focuses on the Covid-19 transmission rates in the original EU-15 countries. EU-15 countries share many similar features in terms of population structure, social and health indicators as well as economic coherence. These similarities help minimize the impact of major confounders in cause and effect relationships we are interested in studying. A total of 60 days is covered since each country's 100th reported case. The 100th case is often used in literature as a benchmark when referring to Covid-19 experience. This is possibly a standardization attempt due to heterogeneity of testing practices and volumes at the initial stages. However, once each country has had 100 confirmed cases, it is safe to assume that more widespread testing and contact tracing would be in order. Daily high temperatures

are used in correspondence with the daily case numbers for the 60-day period for each country.

Case numbers are adopted from the European Center for Disease Prevention and Control [14] while daily temperatures are taken from Ref. [15]. Years of education is used as a proxy for increased awareness of protective health behavior. Country based education statistics come from Refs. [16,17]. The following variables have been used in the model:

PrevRate represents the rate of growth of the daily case numbers for the fifteen countries used in this analysis. A logarithmic transformation is applied to the case numbers in an attempt to reduce data variability. Moreover, given that different countries employ different strategies, number of tests administered to the general population can significantly vary across the countries. Therefore, rather than absolute numbers, the rate of change in numbers will be of more assistance for the purpose of our analysis. Hence, we use the first difference operator.

Temp variable is used for the daily average temperatures in the cities where disease transmission is most pronounced. Cities and associated summary statistics are given in [Table 1](#) below.

Edu represents logarithmic transformation of the mean years of schooling for each country. 2018 statistics are used for the mean years of schooling for each country.

Cont is a dummy variable used for containment measures used by the relevant governments. A value of 1 is assigned for the days strict measures are introduced by the governments and a value of 0 is assigned for the days when these measures are not in effect. [Table 1](#) provides an overview of the summary statistics for each city/country used in this study:

[Figure 1](#) provides an overview of the case growth rates in each of the EU-15 countries separately for the 60-day period use in this study.

Table 1 Summary statistics.

City	Country	Temperature Min-Max and Average (Celsius) ^a	Average Years of Schooling	Length of time to government response ^b	Total Cases per million ^c
Vienna	Austria	3-24 (Av. 16.2)	12.1	8 days	1,968
Brussels	Belgium	7-24 (Av. 15.0)	11.8	12 days	5,295
Copenhagen	Denmark	4-20 (Av. 10.9)	12.6	4 days	2,201
Helsinki	Finland	0-16 (Av. 8.3)	12.4	4 days	1,301
Paris	France	8-25 (Av. 17.0)	11.5	11 days	2,516
Munich	Germany	3-24 (Av. 13.2)	14.1	22 days	2,332
Athens	Greece	11-26 (Av. 19.9)	10.8	1 day	325
Cavan	Ireland	6-19 (Av. 12.4)	12.5	9 days	5,157
Milan	Italy	10-24 (Av. 18.0)	10.2	15 days	3,977
Luxembourg	Luxembourg	6-23 (Av. 16.1)	12.1	1 day	6,800
Tilburg	Netherlands	7-23 (Av. 13.7)	12.2	9 days	2,931
Porto	Portugal	13-32 (Av. 18.9)	9.2	5 days	4,110
Madrid	Spain	12-25 (Av. 17.0)	9.8	12 days	6,332
Stockholm	Sweden	2-18 (Av. 9.4)	12.4	12 days	6,700
London	U.K.	8-24 (Av. 15.1)	12.9	18 days	4,595

^a Daytime highest temperatures are used for the purpose of this study. The min versus max values are the minimum and maximum highest daytime temperatures for the 60-day period. Daytime average high temperature is given in brackets.

^b Length of time to government response measures the number of days after the 100th case has been announced until isolation/lockdown measures are initiated.

^c Total cases per million population are recent as of 30/06/2020.

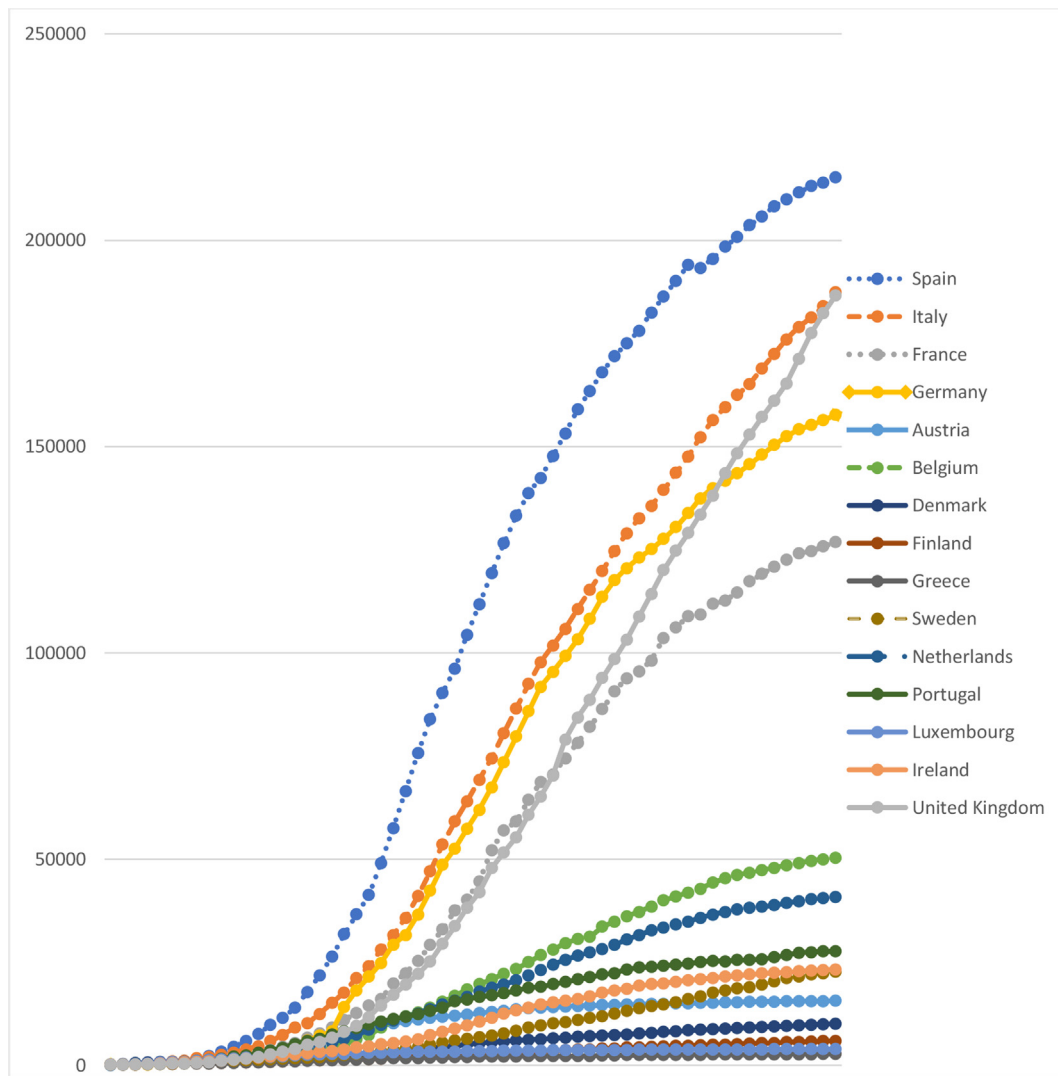


Figure 1 Covid-19 Case Number Growth Since 100 Cases. Source: Own depiction from ECDC data (2020).

Spain, Italy, United Kingdom, Germany and France have, by far, the fastest case growth experience in the EU-15 countries. What these countries have in common is, they all have a government response times over 10 days. However, a closer analysis is required to measure the precise effect of each variable on case growth rates in order to draw more reliable conclusions.

Techniques

Panel data approach allows the use of multi-dimensional data with cross-sectional and time-series aspects in an attempt to unravel relationships across time and space. Panel data models use a number of estimation approaches. OLS estimation with pooled panel tends to be the most simplistic approach. However, pooled panel OLS does not recognize unique attributes between the cross-sectional entities (different countries used in this analysis). In other words, cross-sectional entities are assumed to be homogeneous. When we consider biological, environmental, and

cultural differences, to name a few, across world populations, accepting homogeneity across world populations does not sound like a reasonable argument. As a result, in this paper, we consider random and fixed effects models which take into consideration cross-country heterogeneities as well as cross-country and time-series heterogeneities, respectively. Wu Hausmann test helps identify the right model when estimating panel data output. Based on our test results, the null hypothesis of random effects cannot be rejected, therefore, the variable effects model appears to be more suitable for the current paper [18].

This study estimates three equations in an attempt to explain the effect of years of schooling and temperature variations on Covid-19 transmission. A dummy variable also enters the equation in an attempt to isolate the effects of government containment measures on transmission rates. These models are as follows:

$$\text{PrevRate} = f(\text{Temp}) \quad (1)$$

$$\text{PrevRate} = f(\text{Temp}, \text{Edu}) \quad (2)$$

Table 2 Panel data estimates.

	Pooled Panel	Pooled Panel	Pooled Panel	Variable Effects	Variable Effects	Variable Effects
Model	PrevRate = f(Temp)	PrevRate = f(Temp, Edu)	PrevRate = f(Temp, Edu, Cont)	PrevRate = f(Temp)	PrevRate = f(Temp, Cont)	PrevRate = f(Temp, Edu, Cont)
Variable						
Constant	0.179*** (17.63) <0.00>	0.348*** (8.68) <0.00>	0.490*** (15.92) <0.00>	0.224*** (17.76) <0.00>	0.430*** (6.00) <0.00>	0.497*** (15.40) <0.00>
Temp	-0.006*** (-8.83) <0.00>	-0.007*** (-9.91) <0.00>	-0.004*** (-8.21) <0.00>	-0.009*** (-12.13) <0.00>	-0.009*** (-12.53) <0.00>	-0.005*** (-8.61) <0.00>
Edu	-	-0.013*** (-4.35) <0.00>	-0.013*** (-6.04) <0.00>	-	-0.017*** (-2.90) <0.00>	-0.014*** (-5.83) <0.00>
Cont	-	-	-0.198*** (-25.80) <0.00>	-	-	-0.196*** (-25.87) <0.00>
R ²	0.08	0.10	0.49	0.14	0.15	0.49

Note: *, ** and *** denote significance at 10%, 5% and 1%, respectively. In the constants row, the first number represents the coefficient for the variable. Numbers in parentheses show the t-statistics for each coefficient. Numbers in angle brackets depict the probability statistics. R² is used for the goodness of fit of the model estimation.

$$\text{PrevRate} = f(\text{Temp}, \text{Edu}, \text{Cont}) \tag{3}$$

Results

Table 2 below provides the estimation output for the three equations specified in this paper, using pooled OLS estimates as well as the estimates for the variable effects model.

The variable effects model estimates are quite similar to the pooled panel estimates. This could perhaps be due to a careful selection of the countries in an attempt to minimize cross-country heterogeneities in various domains such as the economy, social life and healthcare. It is quite plausible that countries used in this study already show coherence in many of these domains of life, thus, allowing us to better isolate the effects of the variables in question.

Based on the variable effects estimates, equation (1) suggests a small, but statistically significant negative association between temperature. R² is quite small, which is an expected finding given that temperature is only one factor that may affect viral transmission. The coefficient for temperature is found to be -0.009, which suggests that a 1-degree Celsius increase in the external air temperature is likely to reduce Covid-19 transmission by 0.9 percent. When education is added into the equation, we receive the results depicted on the fifth column. Addition of education as a behavior proxy increases the R² to 0.15, meaning, temperature and education together can help explain 15 percent of the Covid-19 growth rate in the EU-15 countries. The coefficient for education is found to be -0.017, suggesting that each additional year of education can possibly

reduce the Covid-19 growth rate by 1.7 percent. This is also a statistically significant finding as evidenced by its probability statistic. In our variable effects estimates, the sixth and final column depicts results with containment measures being added to the equation. The major finding with the use of this equation is the dramatic increase in the goodness of fit, namely, the R². While containment measures introduced by different governments can vary across countries, adding a dummy variable to separate the time periods with and without containment measures adds a dramatic explanatory power to our equation. A coefficient of -0.198 represents a 19.8 percent reduction in Covid-19 case growth rate.

Discussion

Covid-19 pandemic is an uncharted territory for the world's population. Countries are seeing measures they would have never considered under democratic governance. The current study uses data from countries with sufficient length of Covid-19 incidence data in an attempt to explain the role of outside air temperatures on viral transmission rates to foresee whether summer months may experience lower incidence rates. The impact of human factors such as health behavior is explored using education as a proxy. Moreover, government-imposed containment measures are assessed with respect to their effects on the rate of disease transmission. The preliminary evidence suggests that containment measures are highly effective in slowing down the spread of Covid-19. Years of education also appears to have a small but negative association with disease

transmission rates. Therefore, one could argue that populations with higher educational attainments may be doing a better job of self-protection. Temperature appears to have a very small impact on the viral transmission rate. However, it is a statistically significant impact. It is quite possible that we may not have yet experienced a threshold temperature which may have more pronounced effects on viral activity.

While it is unfortunate, case numbers continue to increase, and it is quite likely that more countries will soon have sufficient data for a larger panel data study. Therefore, further research is required in the upcoming days or weeks to study data with longer time length. It will be important to attempt a similar study by observing wider temperature differentials with a higher number of countries from different geographical regions.

Ethics

No human or animal samples have been used in this study; therefore, ethics approval has not been necessitated.

Authorship statement

This is to certify that the attached paper titled "Understanding Covid-19 Transmission: The Effect of Temperature and Health Behavior on Transmission Rates." is the original work of the author listed on this manuscript and is not being considered for publication elsewhere. All the sources have been referenced and authors given credit to.

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Conflict of interest

No conflict of interest to declare.

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