COVID-19 Pandemic Waves: Identification and Interpretation of Global Data

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Abstract

The mention of the COVID-19 waves is as prevalent as the pandemic itself. We scientifically identify waves and the breaking points at which they begin and end from the beginning of the pandemic till June 2021. We use the Break Least Square method to determine the significance of COVID-19 waves for global-, regional-, and country-level data. The results show that the method works efficiently in detecting different breaking points. Identifying waves at the country level is more relevant than global or regional levels. Once it begins, and irrespective of the circumstances, the COVID-19 wave takes about 48 days on average to subside. Identifying the correct breaking points is critical to evaluate the impact of various COVID-19 variants and the different pharmaceutical and non-pharmaceutical interventions.

Introduction

Whether it is Malthus¹ or Harari², humanity has remained preoccupied with the three challenges of famine, war, and plague. More people have died from diseases than war and famines put together. Historically populations were kept low and dispersed by a high death rate driven by infection³. The pandemic threat has multiplied with greater globalization, urbanization, and connectivity⁴. Plague, for example, has been described as a disease of trade⁵. By mid-January 2022, COVID-19 has infected 313 million and resulted in over 5.5 million reported deaths around the globe. Like the Spanish flu pandemic of 1918⁷, COVID-19 has also occurred in waves. However, there is limited evidence on whether these waves originate from the nature of the disease, pharmaceutical, non-pharmaceutical interventions, or human behaviour⁸. Nevertheless, the COVID-19 waves have played a critical role in the public policy discussions and their implementation. To contain the COVID-19 waves, multiple measures have been adopted globally, including school closings, travel restrictions, bans on public gatherings, emergency investments in healthcare facilities, pharmaceutical interventions, new forms of social welfare provision, contact tracing, etc.⁹ In this paper, we scientifically identify COVID-19 waves and the breaking points at which they begin and end from the beginning of the pandemic till June 2021.

From the days of the 1918 influenza pandemic, researchers, policymakers, and other stakeholders have been interested in understanding the epidemic waves to effectively manage the pandemic with better communications policies and actions^{10,11}. The SIR¹² or complex networks^{13–15} is commonly used to describe the exponential spread of the disease. Unlike a "spike", which is a temporary increase in new COVID-infections, the "wave" may be calibrated as a "sustained" period of the upward and downward period¹⁰.

Employing Break Least Square regression (BLS) on the Johns Hopkins Center for Systems Science and Engineering (CSSE) (2019) data⁶ from the beginning of the pandemic to June 2021, we perform global,

regional, and country level analysis. The spread of the infection is measured using the effective reproduction rate (R_t , hereafter reproduction rate) as estimated by Arroyo-Marioli et al. (2021)¹⁶. They combine the basic epidemiological theory with standard time-series filtering techniques (Kalman) to estimate a transparent closed-form estimator. R_t measures the real-time average number of secondary cases produced by a primary case, as adjusted for the depletion of susceptible individuals and changes in control measures, contact rates, and climatic conditions. For example, in January 2020, the basic reproduction rate (R_0) in Wuhan, China, was calculated to be between two and three; however, after the lockdown, estimates put the R_t at just over one¹⁷. R_t is critical for evaluating public policy decisions during a pandemic^{18,19}. Some social scientists argue that $R_t < 1$ should be taken as a sign for restricting the use of public policy for the pandemic²⁰.

After testing the data for stationarity (Supplementary Information (SI) Tables 1a, 1b), the BLS is estimated for identifying the structural breaks and associated segments on the unadjusted and adjusted effective reproduction rate (where we replace R_t equal to 1 when $R_t < 1$). The data is adjusted to avoid possible misidentification of the start date of a wave where there is a switch from low R_t ($R_t < 1$) values, but this could result in a longer COVID wave duration. We choose 1.1, which is the mean of R_t as the cut-off value (refer to Table 1a in SI), to identify the wave segments. For further details on the method, refer to SI.

The analysis is conducted at the global, continent, and national levels. A subset of countries including the United States; Germany, Italy, France, Netherlands, UK, Spain, and Sweden in Europe; India, South Korea, Japan, and Singapore in Asia; South Africa and Nigeria in Africa; and Brazil and Peru South America are investigated. Our results provide scientific evidence while lending some key insights. We argue that identifying a COVID-19 wave at an aggregate level (global, regional, or continent) has limited policy relevance. For effective policy interventions, pandemic control and impact, identification of waves, and interventions must be performed at the local level. During the first wave, the pandemic's spread and its impact are similar irrespective of the region, given the limited pharmaceutical and non-pharmaceutical interventions. Subsequent waves reflect heterogeneity due to different interventions. Furthermore, once a COVID-19 wave begins, it takes about 48 days before it subsides, irrespective of whether the country/region is developed or how effectively it deals with it.

Results

Global and Regional COVID-19 wave

Declaring global pandemic waves and prescribing policy solutions at the aggregate level is problematic. Figure 1g presents the BLS and adjusted BLS results for the World and captures a single long wave over the study period. The regional (Figure 1) and country level results (Figure 2) show evidence for the greater number of waves. BLS identifies one initial wave of infection for Asia (Figure 1b) for 67 days over the period 23 January to 29 March 2020, with a 1.81 reproduction rate. Similarly, a single wave is identified for the African continent (Figure 1a). These overlap over the same period, though their duration varies. The adjusted BLS identifies that the African wave begins slightly later (15 March 2020), with a mean reproduction rate of 1.52. The length of this first infectious wave is 55 days.

In contrast, two COVID waves are identified for Europe (Figure 1c). The first wave exhibits a high reproduction rate of 2.11 and is 49 days long, extending from 24 February 2020 to 12 April 2020. The second COVID wave is much longer (113 days), plateaus, and is relatively less severe. It has a lower mean reproduction rate of 1.29 and extends from 18 July to 7 November 2020. Evidence shows that North America went through two COVID waves (Figure 1d). The first wave began around 5 March 2020 and ended 48 days later on 21 April 2020. The mean reproduction rate during the first wave was high (2.07). The second wave was initiated on 7 July 2020, with a mean reproduction rate of 1.14. This wave was over 49 days and ended on 24 August 2020.

Oceania and the South American continent witnessed three COVID waves (Figures 1e and 1f). According to the adjusted BLS, Oceania's mean reproduction rate during the first, second and third waves are 1.49, 1.30, and 1.17, respectively. Each of these waves is roughly 48 days long. The first wave begins on 11 March 2020 and ends on 26 April 2020. The second and third waves started (ended) on 16 June 2020 (1 August 2020) and 20 February 2021 (7 April 2021), respectively. The variation in the global and regional/continent results demonstrate that it is imperative to acknowledge the limitations of aggregate data for identifying pandemic waves.

First, much information and variation in the data is lost at the aggregate level (global, regional (continent) or country). Second, taking the mean value of the reproduction rate does not make sense for large countries or for countries where the outbreaks are limited to a few localized areas. Cities with better connectivity and high population density profiles are more susceptible to the initial spread of the virus. At the same time, rural and isolated areas are slow to catch on the infection. Third, the aggregate shocks due to emergent new variants of concern also introduce regional variation in infections²¹. Fourth, data measurement is fraught with reporting errors and lags due to case detection, definitions, testing strategies, reporting practice, and lag times differ between countries/territories/areas²². Fifth, behavioral changes and policy interventions (both non-pharmaceutical and pharmaceutical) impact when and for how long the COVID waves occur.

COVID Waves for Selected Countries

First discovered in Wuhan, China, community transmission of COVID-19 was likely presented in Europe and the USA by January 2020, with international travel as the main driver and transmitted through events between December 2019 and January 2020.²³ Figures 2A, 2B, and 2C present the evidence from the BLS models for the selected countries. In addition, the corresponding breakpoints (start and end dates) of the COVID-19 waves and their length are presented in SI Table 3 for each selected country.

Most European countries have experienced three COVID waves till 30 June 2021. The first wave has high mean reproduction rates (ranging from 1.53 to 1.96) and is 48 days long on average. The initial date of spread is slightly early for Italy (24 February 2020) as compared to France (1 March 2020), the UK (3 March 2020), Germany (2 March 2020), Spain (3 March 2020), Netherlands (7 March 2020) and Sweden (7 March 2020). The second wave has a lower mean reproduction rate but is much longer. While France, Germany, Italy, and Sweden witnessed a 113-118 days long wave, the duration of the second wave for the Netherlands and UK is much longer at 163 and 186 days, respectively. The second wave begins around mid-July and ends around mid-November for most European countries. Netherlands and UK are outliers, with the wave beginning on 13 July 2020 and 8 July 2020 and ending around 23 December 2020 and 9 January 2021, respectively. Spain has a long plateau that extends for nearly one year from summer 2020 to 2021 (361 days).

The third wave is about 48 days long, with mean reproduction rates similar to the second wave. The start and end dates for the third wave vary substantially across countries. The third cycle begins (ends) on 4 March 21 (20 April 2021) for Germany; 7 February 2021 (5 April 2021) for the Netherlands; 14 December 2020 (30 January 2021) for Spain; 26 February 2021 (19 April 2021) for Sweden and 14 May 2021 (30 June 2020) for the UK. The BLS unadjusted data shows the third wave for France (48 days, 4 March – 20 April 2021). The results for other non- EU countries are discussed in SI.

Discussion

This study is not conclusive but indicative of the methods that may be employed to identify the COVID-19 waves. We show that BLS may effectively detect breaking points (start and end) in the effective reproduction rate to identify COVID-19 pandemic waves and their length. We empirically demonstrate that identifying waves at the country or local level is more relevant for interventions than global or aggregate levels. Furthermore, irrespective of the circumstances, once the COVID wave begins, it takes about 48

days on average to subside. It is possible that this figure may change as new COVID variants emerge. Identifying the correct breaking points is critical to evaluate the impact of various COVID-19 variants and the different pharmaceutical and non-pharmaceutical interventions and prescribe effective policy solutions.

Declarations

Author Contributions Bali Swain and Wallentin led the conception and design of the paper and data collection. Lin conducted most of the data analysis, whereas Bali Swain was the main responsible for drafting the paper. The authors jointly conducted the method, interpretation of results and critical revision of the paper.

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Figures

Figure 1

Break Least Square, Adjusted Break Least Square and Reported data for Reproduction Rate for the different Regions/Continents and the World

Figure 2

Break Least Square, Adjusted Break Least Square and Reported data for Reproduction Rate for Selected Countries

Supplementary Files

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