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A COVID-19 Actuarial R0 Primer

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CONTENTS

Section 1: Introduction

As part of its ongoing effort to provide its stakeholders with useful information on the COVID-19 pandemic, the Society of Actuaries (SOA) is continuing to produce reports exploring different aspects of the outbreak. The primary purpose of these reports is to highlight and analyze the vast amount of news and information about COVID-19 and serve as a useful reference for actuaries and other professionals. As well, it is hoped that these reports will stimulate further thinking and approaches for addressing how COVID-19 may reshape the future.

This report has been written to provide a primer on the measurement known as R0 (pronounced “R-naught”), which is commonly used in epidemiology. The R0 metric has received extensive press coverage since the outbreak due to its importance in the measurement of the spread of COVID-19. R0 is known as the basic reproduction number and attempts to measure how fast an infection is spreading in geographical regions and communities. The interest in this measure has been so great that a video of Angela Merkel explaining the meaning of R0 has even been viewed by more than 9 million viewers[1]. Because of a number of assumptions that are part of its calculation, R0 is more difficult to measure than other commonly used COVID-19 metrics (case counts, case fatality rates, recoveries, etc.) and subject to variation from many exogenous factors.

One result of this measurement difficulty is that it is often quoted with a wide range of possible values, resulting in difficulty ascertaining the speed of the spread of a disease. Another concern is that different ways of measuring R0, as well as different time frames used for the calculation, can result in very different values. Additionally, the actual value of R0 is not only a function of the physical characteristics of the virus, but also dependent on the regional area/community characteristics where it is measured, such as population density and pre-existing vulnerability of the population. Other factors include the relative success of social distancing and other preventive policies implemented to stem the spread of the virus. All these factors combined make it difficult for one number to convey the nuances of what is being measured.

Section 2: Background

The idea behind R0, which can be described as a basic reproductive number, is relatively simple. R0 specifies the average number of secondary infections caused by one infected individual during his/her entire infectious period at the start of an outbreak.[2] In its simplest formulation, R0 can be expressed as

$$R0 = \beta\, t \qquad (1)$$

where β represents, for an infectious individual, the average number of infection-producing contacts per unit of time, and t is the number of units of time. If R0 is greater than 1, that implies that each infectious individual is infecting more than one other individual on average – so the outbreak is growing. Conversely, if R0 is less than 1, then each infected individual is infecting fewer than one other individual, so that the number of cases in the population is decreasing. Hence the value of R0 is of great interest for policy-making as it represents whether the disease is still growing or whether it is becoming contained.

[1] https://www.youtube.com/watch?v=22SQVZ4CeXA
[2] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1804098/

R0 can also be useful as a measure of the severity of an infectious disease outbreak. The higher the value of R0 for a disease, the more infectious the disease. A report[3] from the Michigan School of Public Health, shown in Table 1, shows estimated values of R0 for some well-known diseases. The authors note that this article was published on February 12, 2020, so the value shown at the bottom for COVID-19 reflects the R0 value estimates in the early stages of the spread of the disease. More detail about the COVID-19 values, and how they have changed over the course of the outbreak is discussed in Section 4 below.

Table 1

Disease	Reproduction Number R0
Ebola, 2014	1.51 to 2.53
H1N1 Influenza, 2009	1.46 to 1.48
Seasonal Influenza	0.9 to 2.1
Measles	12 to 18
MERS	Around 1
Polio	5 to 7
SARS	<1 to 2.75
Smallpox	5 to 7
SARS-CoV-2 (causes COVID-19)	1.5 to 3.5

Source: https://sph.umich.edu/pursuit/2020posts/how-scientists-quantify-outbreaks.html

As apparent from Table 1, measles is known as being very highly infectious, but this is mitigated by the fact that most of the population has been vaccinated against the disease. The higher number for COVID-19 versus some recent epidemics – like MERS and SARS – reflects the greater impact that COVID-19 has had on public health and the economy than these other diseases.

Section 3: Measuring R0

In the early days of an epidemic, when there are not many infections, epidemiologists may use contact tracing data to estimate R0. Contract tracing refers to the process of identifying contacts of an infected individual who may have therefore been exposed to the disease in order to find them and have them tested. [1] If the spread of the disease were to follow the model described in (1) above, it would represent exponential growth. One approach of estimating R0 would be to determine how long it takes for the number of infected individuals to double, and then estimating R0 based on this doubling time. [4] However, this model is overly simplistic for a number of reasons. For many diseases, including COVID-19, individuals are contagious before they show any symptoms, and this length of time needs to be factored into the model. Also, as previously infected people recover, they may have immunity and not be susceptible to future infection.

In practice, more complex and different approaches are used to measure R0. One example approach uses Bayesian estimation as a way to update the estimate of R0 each time new counts become available. A research article by Luis Bettencourt and Ruy Ribeiro, *Real Time Bayesian Estimation of the Epidemic Potential of Emerging Infectious Diseases,* provides a thorough overview of this approach. [5] An article by Liu, Gable et al, *The reproductive number of COVID-19 is higher compared to SARS coronavirus* provides an inventory of a plethora of potential measurement methods. Table 1 in the article details an extensive list of mathematical models that have been used to analyze the

[3] https://sph.umich.edu/pursuit/2020posts/how-scientists-quantify-outbreaks.html
[4] https://en.wikipedia.org/wiki/Basic_reproduction_number#cite_note-31
[5] https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0002185

COVID-19 infection rates in China.[6] Given the variety of inputs and methods applied to calculating R0 in a rapidly changing environment, it is not surprising that substantially different resulting R0 values may be obtained for some disease outbreaks.

Section 4: Current COVID-19 R0 Estimates

As noted above, the value of R0 is highly dependent on numerous factors. The value also changes with time and varies by the location where it is being measured. The effects of time, geography, social distancing and other measures on the value of R0 for COVID-19 are clearly apparent in a recent report published by the Imperial College London, *Estimating the number of infections and the impact of non-pharmaceutical interventions on COVID-19 in 11 European countries*. [7]

This report shows the typical progression in the values of R0 for COVID-19 as the disease spreads in a population. For many of the countries shown, the best estimates for R0 when the disease was first starting to spread, were in the vicinity of 4. This reflects a situation where nobody had yet gained immunity from exposure to the disease, and when minimal to no policy measures were put in place to limit its spread. As time passed, in the face of the rapid spread of COVID-19, many countries implemented stringent measures to slow the spread ("flatten the curve"). Additionally, the number of susceptible people in the population would have begun to decrease as more people became infected and developed immunity. At present, there is an outstanding question of the extent and duration of immunity after contracting COVID-19. As a result, the impact of immunity on the ensuing spread of COVID-19 remains unclear.

In terms of the progression of COVID-19 R0 estimates, as the spread of the disease has begun to slow in different areas, this reduction is reflected in the decreasing estimates of R0. This is apparent for all the countries listed in the Imperial College London report. After five weeks of measurement, the best estimate values of R0 can be seen to cluster around 1.0.

Due to the multitude of factors that impact the value of R0, there does not appear to currently be a single source containing a global set of local R0 estimates. For the United States, the founders of Instagram launched a website called Rt.live that is an up-to-date tracker of how fast COVID-19 is spreading in each U.S. state. It contains current and historical values of R0 by state, starting on April 11, 2020.[8] Besides the values shown, it provides a useful barometer to show how states that have less rigorous social distancing guidelines generally have a higher level of R0.

Section 5: Considerations and Limitations

Care is needed in the understanding and interpretation of what R0 represents. While this number is promoted in some press articles as being the most important measure for gauging the spread of COVID-19, it is important to understand that no one number can represent the myriad of complexities associated with virus growth, even if the focus is only a single location and time period.

[6] https://academic.oup.com/jtm/article/27/2/taaa021/5735319 [See Table 1]
[7] https://www.imperial.ac.uk/media/imperial-college/medicine/mrc-gida/2020-03-30-COVID19-Report-13.pdf
[8] https://rt.live/

Factors that could impact the value calculated for R0 at any point in time include:

- **Geographical location**. The value of R0 for a location is an average over many smaller geographic units. For example, the R0 associated with a nursing home could be very different from the R0 associated with a neighboring, widely dispersed housing development where individual houses are built on large lots. The average population density of an area will clearly be a critical factor impacting how quickly the disease can spread.

- **Social distancing.** The level of stringency of stay at home and other social distancing measures that have been implemented and the extent of their adherence affect R0 values.

- **Measurement timeframes**. Whenever a rate of change is being measured, the calculated change will be sensitive to the measurement time frame. In the situation of a rapidly spreading virus-- particularly in the early stages of the disease spreading when numbers are smaller and more volatile - the impact of different time frames will be exacerbated.

- **Symptomatic vs asymptomatic cases.** Many of the models rely on baseline assumptions about the number of infected individuals in the population, and the probabilities of those individuals spreading the disease to others. If these inputs are difficult to measure, it will be more difficult for the model to correctly fit data. It has been frequently documented that many individuals with COVID-19 are asymptomatic, making it more difficult to determine the model's parameters. There have also been reports of infected individuals not seeking medical treatment because they do not want to risk going out into the public, making it more difficult to correctly count the number of infections.

- **Testing difficulties.** Many of the current tests for COVID-19 have been subject to significant testing errors – both for false positives and false negatives.[9]

- **Modeling methods used.** Different models require varying inputs and utilize different assumptions and computation methods, resulting in a range of calculated values of R0.

Section 6: Conclusions

The value of R0 provides a useful guide to understanding how quickly a disease is spreading in a geographical area/community. A value of R0 greater than 1 indicates that the number of infected individuals in each generation of infections is increasing and so the disease will continue to spread. A value less than 1 shows that each generation of infected individuals is smaller than the last, so that the disease is receding.

Because the value of R0 is impacted by many factors - such as the timeframe during which it is measured and steps taken to mitigate the spread of the disease – the value of R0 needs to be understood in the context of its calculation, not just as one number that fully represents the infectiousness of a disease.

Generally, the value of R0 is higher when a disease starts spreading in a population, and then gradually decreases over time as interventions are implemented. The changing value of R0 provides useful information about the effectiveness of such interventions.

[9] https://www.forbes.com/sites/startswithabang/2020/05/07/this-is-how-false-positives-and-false-negatives-can-bias-covid-19-testing/#453969a31743

There are many models available to estimate the value of R0, and different methods could produce significantly different results.

Despite its limitations, R0 will likely continue to be a closely watched measure by public health and government officials in setting policies to address COVID-19.

The SOA is closely monitoring the rapidly evolving COVID-19 situation and will continue to provide research communications that further explore the impact of this pandemic.

About The Society of Actuaries

The Society of Actuaries (SOA), formed in 1949, is one of the largest actuarial professional organizations in the world dedicated to serving more than 31,000 actuarial members and the public in the United States, Canada and worldwide. In line with the SOA Vision Statement, actuaries act as business leaders who develop and use mathematical models to measure and manage risk in support of financial security for individuals, organizations and the public.

The SOA supports actuaries and advances knowledge through research and education. As part of its work, the SOA seeks to inform public policy development and public understanding through research. The SOA aspires to be a trusted source of objective, data-driven research and analysis with an actuarial perspective for its members, industry, policymakers and the public. This distinct perspective comes from the SOA as an association of actuaries, who have a rigorous formal education and direct experience as practitioners as they perform applied research. The SOA also welcomes the opportunity to partner with other organizations in our work where appropriate.

The SOA has a history of working with public policymakers and regulators in developing historical experience studies and projection techniques as well as individual reports on health care, retirement and other topics. The SOA's research is intended to aid the work of policymakers and regulators and follow certain core principles:

Objectivity: The SOA's research informs and provides analysis that can be relied upon by other individuals or organizations involved in public policy discussions. The SOA does not take advocacy positions or lobby specific policy proposals.

Quality: The SOA aspires to the highest ethical and quality standards in all of its research and analysis. Our research process is overseen by experienced actuaries and nonactuaries from a range of industry sectors and organizations. A rigorous peer-review process ensures the quality and integrity of our work.

Relevance: The SOA provides timely research on public policy issues. Our research advances actuarial knowledge while providing critical insights on key policy issues, and thereby provides value to stakeholders and decision makers.

Quantification: The SOA leverages the diverse skill sets of actuaries to provide research and findings that are driven by the best available data and methods. Actuaries use detailed modeling to analyze financial risk and provide distinct insight and quantification. Further, actuarial standards require transparency and the disclosure of the assumptions and analytic approach underlying the work.

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