An analysis of how three varying approaches to COVID-19 could have influenced the number of infections in the UK and Sweden

**Introduction to Mathematics**

**Group Project**

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**Group 1:** (anonymized)

**INTRODUCTION**

The ongoing coronavirus (COVID-19) pandemic is the fifth recorded pandemic since the Spanish flu of 1918.[[1]](#footnote-1) The disease first reported in the Hubei Province of China as a new strand of the coronavirus SARS-CoV-2[[2]](#footnote-2) causes *acute respiratory illness[[3]](#footnote-3).* The highly contagious nature of the virus has seen the world descend into a global health crisis. With over 45.4 million cases reported worldwide and approximately 1.2 million COVID-related deaths, the epidemic has become the source of social, political, and economic upheaval.[[4]](#footnote-4) In the last 11 months, countries have been divided over appropriate measures and solutions. The varying responses to the outbreak from early full-scale lockdown, to loose social distancing, have shown markedly different infection and recovery rates. Countries like Thailand, Hong Kong, Taiwan, and Singapore have amongst the lowest rates of COVID-19. [[5]](#footnote-5) Alongside this, Australia and New Zealand pivoted from the flu pandemic model to the East-Asian SARS model, which is continuing to eliminate the virus. Such countries have returned to ‘normality’ while others, such as the UK continue to overwhelm healthcare systems.

It is clear that with the right restrictions, cases can be managed, and transmission prevented. Amidst the largest influx of cases in the UK seems an appropriate time to glance across at our global neighbours and consider what may have been done differently. In pursuit of this, this project aims to create a model, using Leslie matrices, that maps the spread of infection in the general populations of two example countries: the UK and Sweden. These two countries are amongst the most criticised for their COVID policies, with Sweden having ‘the highest death rates relative to population size in Europe’ and the UK’s see-saw policies of granting and revoking freedoms. [[6]](#footnote-6)The UK’s late lockdown, and Sweden’s ‘herd immunity’ were compared in the media, with many divided over giving the models credence, and chastising them. With these divisions in mind, this model will be constructed to understand the influence of isolation (or lack of adequate measures) in managing the virus — mirroring both Sweden and the UK’s responses — across three scenarios. As such, we will assess data from both country’s first case (February 1st) until the UK’s national lockdown (March 23rd) to build a model. The chosen scenarios take different measures to the virus — we will consider the risk of no isolation measures, then isolation after two days, and then isolating before contact (a full-scale lockdown). The model will consider the following variables across the UK and Sweden: uninfected population, infected asymptomatic not infectious, infected asymptomatic infectious, infected symptomatic infectious, infected symptomatic post-infectious, recovered from infection, fatalities, and, all infected.

The project will include various models, followed by extensive analysis and discussion, to gain insight into the most effective COVID measures as the world continues to grapple with the disease. Given the current global environment, the pandemic overshadows much in terms of relevance. Using this example, that is relevant beyond the field of maths, we will apply mathematical modelling to greater enhance our understanding and analysis of the current situation in which we find ourselves.

**MODELLING ASSUMPTIONS**

In establishing our method, we first aimed to obtain data on the UK and Sweden, which we found at: <https://ourworldindata.org/coronavirus>. This site will be used for all data from this point forward. Utilising this, we began to form the variables we would need for our models:

a = The given population of either country

b = Infected asymptomatic not infectious individuals

c = Infected asymptomatic infectious individuals

d = Infected symptomatic infectious individuals

e = Infected symptomatic postinfectious individuals

f = Recovered from infection

g = Fatalities

h = Cumulative number of infected

Diagram

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Figure 1: Flowchart explaining the different states of infection

The raw data for h (only) is shown in Appendix A, and through working from a number of assumptions, we will calculate the values of the remaining variables in order to build our model.

Our fundamental goal is to, using data obtained between 1st February and the 23rd March, create a linear model which will explain the increase in cases for that period. Using this model, we will then examine three scenarios to establish how varied timeframes before isolation would affect the spread of Covid-19 among the general population. Sweden and the UK were chosen as they both recorded an initial case on 1st February and as of 23rd March, they had similar rates of infection when adjusted for population (see figure 3). Yet, as of October 30th, the UK reported 965,340 cumulative cases, whereas Sweden (when adjusted for population) had 835,666 cases, roughly 15.5% fewer cases.

Chart, line chart

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 Figure 2: Cumulative cases for the UK and Sweden

Before beginning to analyse the data to create a model, we must assert some assumptions. First and foremost, the use of linear models must be addressed. We acknowledge the simplicity of linear models as they pertain only to mapping relationships along a straight line. Whilst this does sacrifice accuracy, it can prove simple yet effective in establishing broad relationships. Likewise, we acknowledge an assumption of constant error variance and indeed a homogeneity of the data, something which is clearly not the case when mapping something so analogous to human behaviour as the spread of a disease. However, it is necessary as we cannot hope in such a simple model to map individual human behavioural tendencies. This is to say that Covid-19 relies on the transmission from one infected individual to a non-infected individual and thus it travels not as a constant through any population but as a product of interaction between individuals. This means that infections will often reflect social or geographical boundaries in accordance with interactions and thus may not be representative of entire populations. We must also assume a constant infection rate. Assuming the average infectious person (variables c & d) has an incubation period of 6 days from initial exposure, and that the average person infects 2-3 people[[7]](#footnote-7), we assert a constant daily exposure of 0.5 people for those not in isolation. This relies further on the assumption that upon developing symptoms, those individuals would isolate, reducing their infectability to zero. Further, we assume an equal likeness for any infected person to spread the disease at any given time (t).

Another assumption is a standard two-week recovery period, not accounting for long-term hospitalisations or continued treatment, as this data is not as freely available. Finally, we assume that for the purposes of this model and due to the limited time scale examined, that those that have already contracted the disease cannot do so again. This is based on preliminary research that suggests COVID immunity lasts between 5-7 months and we are only looking at 30 days into the future[[8]](#footnote-8). The most difficult assumption, and indeed the one that may prove most critical is the breakdown of individuals into infectious or non-infectious and symptomatic or asymptomatic. The University of Oxford’s analysis of 21 differing reports puts the range at between 5-80% asymptomatic, [[9]](#footnote-9) though we assume a conservative estimate, based on Centre for Disease Control numbers (featured within the Oxford analysis) and a report by Al-Tawfiq, [[10]](#footnote-10) at 20%. We in turn assume that those 20% of asymptomatic individuals are equally split between infectious and non-infectious. This number is an average that reflects all demographics, though in reality it would appear that attributes like age and nationality affect the presence of symptoms (see Oxford report), which this model cannot account for. The remaining 80% of infections, which we assume are symptomatic, are again equally split between those that are infectious and those that are not. This is mainly due to a lack of available information to suggest otherwise.

The Leslie matrix is often used to model growth of age-structured populations by monitoring the proportion of individuals from different age classes who move on to the next age class (survival rate), as well as the rate per capita of new births arising from each category (birth rate). This model will allow us to demonstrate the proportion of the population at each stage of the infection (not yet infected, infected, recovered etc). We can then predict how many cases of SARS-Cov-2 we would expect after 30 days in each country if we start with a given number of infectious people and adopt different approaches throughout the infectious period.

This is an example of a Leslie matrix:

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Where:

Using a similar model will allow us to demonstrate the proportion of the population at each stage of the infection (not yet infected, infected, recovered etc). We can then predict how many cases of SARS-Cov-2 we would expect after 30 days in each country if we start with a given number of infectious people and adopt different approaches throughout the infectious period.

**DATA**

We set out to find the accurate amount of people at each stage of the infection (a...h) on March 23rd, see Appendix B for full details. These would be our values at t0 (March 23rd). So, drawing on raw data from *OurWorldInData*, we first obtained the total daily positive cases from 1st February-23rd March in UK (8,390) and Sweden (1,987).[[11]](#footnote-11) We subtracted those that would have already recovered by March 23rd based on the previously mentioned assumption that infected people recover within 14 days i.e. by March 9th, (408 for UK, 225 for Sweden). We also subtracted the fatalities up until 9th March for each country (0 for UK, 2 for Sweden).

We were left with 8,522 positive cases for the UK and 1,762 cases for Sweden. We calculated the proportion of asymptomatic (20%) and split this evenly for infectious asymptomatic carriers c (852 for UK, 176 for Sweden) and non-infectious asymptomatic carriers, b (852 for UK, 176 for Sweden). The subsequent 80% were taken to be symptomatic carriers and this also split evenly for infectious symptomatic carriers, d (3,409 for UK, 705 for Sweden) and non-infectious symptomatic carriers, e, (3,409 for UK, 705 for Sweden). Finally, we subtracted the number of fatalities within the time period 1st Feb-March 9th, g, (2 for UK, 0 for Sweden) and subtracted this from total number of cases up to March 9th to get number of recovered f (406 for UK, 225 for Sweden). We could therefore conclude that on 23rd March the total number of infected people, h, was 8,928 for the UK and 1,987 for Sweden and that the total number of non-infected people was the rest of each population (66,638,069 for UK, 10,228,013 for Sweden).

**METHOD**

This report will attempt to make predictions for three different scenarios, analysing their outcomes should they have been adopted in the UK and Sweden on the 23rd March 2020.

Around mid-March, the UK considered herd immunity as a response. [[12]](#footnote-12) This was the general approach of the Swedes who ‘avoided a lockdown and instead emphasized personal responsibility, social distancing and good hygiene in a bid to slow rather than eradicate a disease deemed here to stay.’[[13]](#footnote-13) In light of this:

*Scenario 1* was chosen to convey the situation had a lockdown never been implemented in either country. As previously mentioned, this scenario will assume a constant daily exposure of 0.5 people. In a bid to narrow our search, we chose two further examples that catered for somewhat of a mid-point, as well as another ‘extreme’.

In turn, S*cenario 2* predicts future figures of positive cases providing that positive individuals isolated after day two of the infectious period. It also assumes a constant daily exposure of 0.167 people. This assumption was based on the fact that if each person isolates after two days, they infect one person over the two days, therefore we took 1/6 = 0.167. This approach appears plausible and realistic, giving time for track & trace alerts and time taken to obtain a test. It is also an approach that attempts to keep the R number at 1, based on the assumption that the average person infects 2-3 people.

Finally, S*cenario 3* will present the future figures had a full-scale lockdown been implemented in each country on 23rd March (constant daily exposure of 0 people) for a full 30 days.

Table 1 displays the system of linear equations for each scenario, using the assumptions explained previously.

|  |  |  |
| --- | --- | --- |
| Scenario 1 | Scenario 2 | Scenario 3 |
|  |  |  |

Table 1: System of linear equations for each scenario

**Leslie Matrices**

We will use Leslie matrices to solve values of infected people, after 30 applications (30 days) in each scenario.

Start time = 23rd March, which represents the date the UK entered lockdown.

at time , will be the sum of all people who became infected at the previous time step, as well as the people from the previous time step who remain infected.

This can be written as:

Where A = transition matrix

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**CONCLUSIONS**

**Results**

The full breakdown of the results, showing each variable’s values across the different scenarios is displayed in Appendix C. In summary, our findings indicate that if the UK had implemented scenario 1 on March 23rd, there would be 14,291,248 people infected by April 23rd. If positive Covid-19 citizens had isolated on day 2 of the infectious period, there would be 177,423 infected by April 23rd. If the UK had imposed a full-scale lockdown as in scenario 3, then there would be 0 infected by April 23rd, as those infected would recover by day 14.

Along that same vein, in Sweden, these figures come out to 2,969,689 infected for scenario 1. In scenario 2 that figure would drop to 33,988 and in a full-scale lockdown there would be 0 infected by April 23rd.

In reality, on 23rd April there were 134,879 people infected[[14]](#footnote-14) in the UK and 16,553 in Sweden. In the UK lockdown was imposed on the 23rd March, and therefore one would expect a trajectory showing something in between that of scenario 2 and 3. Our results corroborate this notion as the actual figure (134,879) is between scenario 2’s prediction (177,423) and 0. In an ideal world, such as that of the model, those that show symptoms isolate soon after, however, in real life we know this is not the case. As a result, you would expect a figure closer to that of scenario 2 than a total lockdown as people may mistake Covid-19 for the common cold or be reluctant to isolate and continue their daily lives, making the virus almost impossible overcome.

**Importance of the Model**

This report has collated and manipulated raw data to construct a mathematical model which may be used to make predictions with regard to the spread of Covid-19. The model takes into account a number of variables, including a distinction between the varying stages of infection and whether or not symptoms are apparent. The 2002 SARS outbreak only amassed to around 8000 cases, whereas Covid-19 is not too far off 50 million cases worldwide. One of the reasons for this large disparity is that SARS incurred much more obvious symptoms, and therefore it was much easier to detect and isolate those individuals showing symptoms. Our model has attempted to incorporate the effect of asymptomatic carriers to provide a more accurate prediction.

**Implications for Future Strategies**

We can try and deduce which future strategy would be the most effective with regard to mitigating the proliferation of the virus. Considering the UK implemented a lockdown during the period that we investigated, the fact that the actual figure is lower than the predicted figure for scenario 2 suggests that lockdown was the right move at the time. The R rate was extremely high and due to the population density of the country, as shown by scenario 1 a ‘herd immunity strategy’ would have resulted in far more cases and subsequent fatalities. When compared with Sweden, who opted more for a ‘herd immunisation’ approach, it appears that their approach worked well, with only around 16,000 infected during the time period. Furthermore, it is often cited in the media that Sweden’s situation is not as glamorous as it appears on face value. When the notion of population size is accounted for with regard to deaths, Sweden is not too far off the UK with around 580 deaths per million of the population. And when juxtaposed with neighbouring countries such as Finland, who have a mere 62 deaths per million, the figures do not look as commendable, and perhaps they should have implemented a scenario 2 or 3 style lockdown.

**Limitations**

It must be said that the model is a very simplified one and obviously falls short of capturing the complexities of real life. Having said that, no model is perfect, but it still provides us with valuable information and predictions.

This model assumes that the R rate is 3, meaning someone infects on average 3 other people during their infectious period. This is an oversimplification as the R rate fluctuates all the time, plus it varies greatly across regions. There is likely to be disparities between the rates of the UK and Sweden, however, there was not enough data at that time to ascertain the differing rates accurately. Furthermore, the model assumes that one cannot contract the virus twice. However, there have been multiple cases where someone has contracted the virus more than once, which appear to refute the model. However, re-infection is likely to be rare and thus a more sophisticated model would be needed where those that recover become susceptible once again.

Another limitation is that the model does not incorporate the latency period between when an individual is exposed to the virus and when they become infected and contagious. It is assumed that those that contract the virus are immediately infectious, however, this is not the case as people are likely to have a delay of a few days before they show symptoms and can pass it on.

**Further Applications of the Model**

We believe our model has further potential. The eigenvectors (see Appendix D) of the matrices would provide the stable distribution of the various groups -- i.e the proportion of the total population in each group -- which would remain constant until exponentials appeared. Once this distribution has been reached -- i.e the R number becomes too high -- the infected population would begin to undergo exponential growth rate. The eigenvalue would be the growth rate.

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**APPENDIX**

**Appendix A**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Date | New Daily Cases (UK) | New Daily Cases (Sweden) | Running Total (UK) | Running Total (Sweden) |
| 01/02 | 2 | 1 | 2 | 1 |
| 05/02 | 1 | 0 | 3 | 1 |
| 07/02 | 1 | 0 | 4 | 1 |
| 13/02 | 1 | 0 | 5 | 1 |
| 14/02 | 1 | 0 | 6 | 1 |
| 23/02 | 1 | 0 | 7 | 1 |
| 26/02 | 2 | 0 | 9 | 1 |
| 27/02 | 5 | 1 | 14 | 2 |
| 28/02 | 4 | 1 | 18 | 3 |
| 29/02 | 8 | 8 | 26 | 11 |
| 01/03 | 12 | 3 | 38 | 14 |
| 02/03 | 5 | 0 | 43 | 14 |
| 03/03 | 22 | 5 | 65 | 19 |
| 04/03 | 40 | 13 | 105 | 32 |
| 05/03 | 55 | 30 | 160 | 62 |
| 06/03 | 56 | 25 | 216 | 87 |
| 07/03 | 51 | 59 | 267 | 146 |
| 08/03 | 81 | 33 | 348 | 179 |
| 09/03 | 60 | 46 | 408 | 225 |
| 10/03 | 57 | 101 | 465 | 326 |
| 11/03 | 148 | 98 | 613 | 424 |
| 12/03 | 259 | 196 | 872 | 620 |
| 13/03 | 406 | 151 | 1,278 | 771 |
| 14/03 | 484 | 152 | 1,762 | 923 |
| 15/03 | 478 | 71 | 2,240 | 994 |
| 16/03 | 361 | 69 | 2,601 | 1,063 |
| 17/03 | 442 | 83 | 3,043 | 1,146 |
| 18/03 | 611 | 119 | 3,654 | 1,265 |
| 19/03 | 769 | 145 | 4,423 | 1,410 |
| 20/03 | 999 | 143 | 5,422 | 1,553 |
| 21/03 | 1,055 | 180 | 6,477 | 1,733 |
| 22/03 | 1,255 | 136 | 7,732 | 1,869 |
| 23/03 | 1,198 | 118 | 8,930 | 1,987 |

**Appendix B**

**Initial calculations drawing on raw data** **from February 1st to March 23rd (UK)**

Total infected for March 23rd = 8930

8930 - 408 = 8522\* including fatalities between March 9th and 23rd

Fatalities between 9th-23rd March = 2

Total fatalities up until 23rd = 288

20% 8522 gives us asymptomatic (b and c) = 1704

We will assume b and c are even (10% each) = 852 each

To get d and e subtract b and c from total infected to get: 6818

We will assume d and e are equal so divide 6818 by 2 to get 3409

Fatalities: 1 March 7th, 1 March 8th (between 1st Feb and 9th March)

 2 deaths within this time period - subtract this from total number of cases up to March 9th to get number of recovered.

408 - 2 = 406 recovered

Total still infected on March 8522

3409 + 852 = total infectious = 4,261

Recovery rate = 95%

* 965338 total cases in the UK up to now
* 45955 total deaths from Covid-19 up to now

Total population of UK = 66.65 mil

Infected population = 8930

Non infected population = 66638069

**na…nh at t0 (23rd March)**

Not infected i.e the rest of the population (a) = 66,638,069

Infected asymptomatic not infectious (b) = 852

Infected asymptomatic infectious (c) = 852

Infected symptomatic infectious (d) = 3409

Infected symptomatic postinfectious (e) = 3409

Recovered from infection (f) = 406

Fatalities (g) = 2 or 288

All infected (h) = 8928

**Initial calculations drawing on raw data** (Sweden):

Total infected up to March 23rd = 1987

1987 - 225 = 1762\* including fatalities between March 9th and 23rd (which was zero)

Fatalities between 9th-23rd = 0

Total fatalities up until 23rd = 58

20% of 1762 gives us asymptomatic (b and c) = 352

We will assume b and c are even (10% each) = 176 each

For d and e, subtract b and c from total infected: 1762-352 = 1410

We will assume d and e are even (40% each) so divide 1410 by 2 to get 705

Total still infected at t0: 1762

1410 + 176 = total infectious = 1,586

Recovery rate = 95%

* 121,167 total cases in Sweden up to now
* 5,934 total deaths from Covid-19 up to now

Total population of Sweden = 10.23 mil

Total infected = 1987

Non infected population = a = (10230000-1987) = 10228013

**na…nh at t0 (23rd March):**

Not infected i.e the rest of the population (a) = 10228013

Infected asymptomatic not infectious (b) = 176

Infected asymptomatic infectious (c) = 176

Infected symptomatic infectious (d) = 705

Infected symptomatic postinfectious (e) = 705

Recovered from infection (f) = 225

Fatalities (g) = 0 or 58

All infected (h) = (assuming we include recovered/not currently infected) 1,987

**Appendix C**

|  |  |  |  |
| --- | --- | --- | --- |
| UK | Scenario 1 (t+30) | Scenario 2 (t+30) | Scenario 3 (t+30) |
| a | 55,306,630 | 66,431,653 | 66,631,716 |
| b | 6,239,547 | 16,510 | 0 |
| c | 1,126,753 | 16,510 | 0 |
| d | 4,528,316 | 82,381 | 0 |
| e | 4,528,316 | 82,381 | 0 |
| f | 2,024,755 | 16,009 | 2,270 |
| g | 106,929 | 4,350 | 112 |
| h | 2,782,592 (should be 14,291,248) | 18,717 (should be 177,423) | 0 |

|  |  |  |  |
| --- | --- | --- | --- |
| Sweden | Scenario 1 (t+30) | Scenario 2 (t+30) | Scenario 3 (t+30) |
| a | 7,866,756 | 101,820,028 | 1,022,6666 |
| b | 1,291,779 | 2,014 | 0 |
| c | 234,804 | 2,014 | 0 |
| d | 943,622 | 17,098 | 0 |
| e | 943,622 | 17,098 | 0 |
| f | 421,188 | 3,335 | 544 |
| g | 22,250 | 901 | 27 |
| h | 579,850 (should be 2,969,689) | 3,974 (should be 33,988) | 0 |

**Appendix D**

**Diagonalised**:

Scenario 1

Diagonal of a matrix : Matrix

([[1.00000000000000, 0, 0, 0, 0, 0, 0, 0],

[0, 1.00000000000000, 0, 0, 0, 0, 0, 0],

[0, 0, 1.00000000000000, 0, 0, 0, 0, 0],

[0, 0, 0, 1.0 - 1.00125027375074e-32\*I, 0, 0, 0, 0],

[0, 0, 0, 0, 0.351091537500545 - 0.806745845591219\*I, 0, 0, 0],

[0, 0, 0, 0, 0, 1.24597746937453 - 5.44693552933307e-32\*I, 0, 0],

[0, 0, 0, 0, 0, 0, 0.0518394556243815 - 3.57253406678237e-32\*I, 0],

[0, 0, 0, 0, 0, 0, 0, 0.351091537500545 + 0.806745845591219\*I]])

Scenario 2

Diagonal of a matrix : Matrix

([[1.00000000000000, 0, 0, 0, 0, 0, 0, 0],

[0, 1.00000000000000, 0, 0, 0, 0, 0, 0],

[0, 0, 1.00000000000000, 0, 0, 0, 0, 0],

[0, 0, 0, 1.0 + 3.78649940071671e-65\*I, 0, 0, 0, 0],

[0, 0, 0, 0, 0.43053737363954 - 0.83279604880301\*I, 0, 0, 0],

[0, 0, 0, 0, 0, 1.08656913954717 + 1.64206474009579e-64\*I, 0, 0],

[0, 0, 0, 0, 0, 0, 0.0523561131737475 - 3.418448939826e-65\*I, 0],

[0, 0, 0, 0, 0, 0, 0, 0.43053737363954 + 0.83279604880301\*I]])

Scenario 3

Diagonal of a matrix : Matrix

([[1.00000000000000, 0, 0, 0, 0, 0, 0, 0],

[0, 1.00000000000000, 0, 0, 0, 0, 0, 0],

[0, 0, 1.00000000000000, 0, 0, 0, 0, 0],

[0, 0, 0, 1.00000000000000, 0, 0, 0, 0],

[0, 0, 0, 0, 1.00000000000000, 0, 0, 0],

[0, 0, 0, 0, 0, 0.473688246659963 - 0.851918524127421\*I, 0, 0],

[0, 0, 0, 0, 0, 0, 0.0526235066800737 - 1.31005175581703e-64\*I, 0],

[0, 0, 0, 0, 0, 0, 0, 0.473688246659963 + 0.851918524127421\*I]])

**Eigenvalues and eigenvectors for scenario 1**

**Eigenvalues:**

[1.        +0.j         1.        +0.j         1.        +0.j

 0.35109154+0.80674585j 0.35109154-0.80674585j 1.24597747+0.j

 1.        +0.j         0.05183946+0.j        ]

----------------------------------------------

**Eigenvectors:**

[[ 1.00000000e+00+0.j          0.00000000e+00+0.j  0.00000000e+00+0.j 2.17876346e-01-0.47910903j    2.17876346e-01+0.47910903j  8.35404918e-01+0.j   -9.25514583e-01+0.j          5.63808324e-01+0.j        ]

 [ 0.00000000e+00+0.j          1.00000000e+00+0.j  0.00000000e+00+0.j         -2.17876346e-02+0.0479109j  -2.17876346e-02-0.0479109j  -8.35404918e-02+0.j

   9.03822835e-02+0.j         -5.63808324e-02+0.j        ]

 [ 0.00000000e+00+0.j          0.00000000e+00+0.j   0.00000000e+00+0.j         -2.17876346e-02+0.0479109j  -2.17876346e-02-0.0479109j  -8.35404918e-02+0.j

  -4.76994992e-02+0.j         -5.63808324e-02+0.j        ]

 [ 0.00000000e+00+0.j          0.00000000e+00+0.j

   0.00000000e+00+0.j         -8.71505385e-02+0.19164361j

  -8.71505385e-02-0.19164361j -3.34161967e-01+0.j

   4.76994992e-02+0.j         -2.25523330e-01+0.j        ]

 [ 0.00000000e+00+0.j          0.00000000e+00+0.j

   1.00000000e+00+0.j         -8.71505385e-02+0.19164361j

  -8.71505385e-02-0.19164361j -3.34161967e-01+0.j

   3.61529134e-01+0.j         -2.25523330e-01+0.j        ]

 [ 0.00000000e+00+0.j          0.00000000e+00+0.j

   0.00000000e+00+0.j         -5.75240257e-01+0.j

  -5.75240257e-01-0.j         -1.50058958e-01+0.j

  -1.73301210e-16+0.j         -1.49695555e-01+0.j        ]

 [ 0.00000000e+00+0.j          0.00000000e+00+0.j

   0.00000000e+00+0.j         -3.09185573e-02+0.00173738j

  -3.09185573e-02-0.00173738j -8.24616788e-03+0.j

  -7.67635365e-18+0.j          5.15611903e-01+0.j        ]

 [ 0.00000000e+00+0.j          0.00000000e+00+0.j

   0.00000000e+00+0.j         -2.45137414e-01-0.48666874j

  -2.45137414e-01+0.48666874j -2.05490788e-01+0.j

  -2.06209499e-16+0.j          5.34580807e-01+0.j        ]]

**Scenario 2:**

**Eigenvalues**

[1.        +0.j         1.        +0.j         1.        +0.j

 0.43053737+0.83279605j 0.43053737-0.83279605j 1.08656914+0.j

 1.        +0.j         0.05235611+0.j        ]

----------------------------------------------

**Eigenvectors**

[[ 1.00000000e+00+0.j          0.00000000e+00+0.j

   0.00000000e+00+0.j         -3.08149318e-01-0.45064509j

  -3.08149318e-01+0.45064509j -8.59804456e-01+0.j

  -9.04202557e-01+0.j          5.71173526e-01+0.j        ]

 [ 0.00000000e+00+0.j          1.00000000e+00+0.j

   0.00000000e+00+0.j          3.08149318e-02+0.04506451j

   3.08149318e-02-0.04506451j  8.59804456e-02+0.j

   8.27014534e-02+0.j         -5.71173526e-02+0.j        ]

 [ 0.00000000e+00+0.j          0.00000000e+00+0.j

   0.00000000e+00+0.j          3.08149318e-02+0.04506451j

   3.08149318e-02-0.04506451j  8.59804456e-02+0.j

  -1.81859451e-01+0.j         -5.71173526e-02+0.j        ]

 [ 0.00000000e+00+0.j          0.00000000e+00+0.j

   0.00000000e+00+0.j          1.23259727e-01+0.18025803j

   1.23259727e-01-0.18025803j  3.43921782e-01+0.j

   1.81859451e-01+0.j         -2.28469410e-01+0.j        ]

 [ 0.00000000e+00+0.j          0.00000000e+00+0.j

   1.00000000e+00+0.j          1.23259727e-01+0.18025803j

   1.23259727e-01-0.18025803j  3.43921782e-01+0.j

   3.30805813e-01+0.j         -2.28469410e-01+0.j        ]

 [ 0.00000000e+00+0.j          0.00000000e+00+0.j

   0.00000000e+00+0.j         -2.74425358e-01+0.47021826j

  -2.74425358e-01-0.47021826j  6.19249947e-02+0.j

  -3.19877239e-16+0.j         -5.16737156e-02+0.j        ]

 [ 0.00000000e+00+0.j          0.00000000e+00+0.j

   0.00000000e+00+0.j         -1.34899337e-02+0.02609382j

  -1.34899337e-02-0.02609382j  3.42511715e-03+0.j

  -3.18849079e-17+0.j          5.16911080e-01+0.j        ]

 [ 0.00000000e+00+0.j          0.00000000e+00+0.j

   0.00000000e+00+0.j         -5.50774968e-01+0.j

  -5.50774968e-01-0.j          7.44325319e-02+0.j

  -4.62933416e-16+0.j          5.41269100e-01+0.j        ]]

1. Liu, Kuo and Shih, 2020 [↑](#footnote-ref-1)
2. *Severe Acute Respiratory Syndrome Coronavirus 2* [↑](#footnote-ref-2)
3. Covid-19 : Oxford English Dictionary, 2020 [↑](#footnote-ref-3)
4. CSSEGISandData/COVID-19, 2020 [↑](#footnote-ref-4)
5. *Of course, there are many benefits to island countries as there is more control over ports of entry in comparison to countries with land borders (like Germany, which has nine).* [↑](#footnote-ref-5)
6. Savage, 2020 [↑](#footnote-ref-6)
7. *Incubation period of 2019 novel coronavirus (2019-nCoV) infections among travellers from Wuhan, China, 20-28 January 2020, Backer, Jantien A and Klinkenberg, Don and Wallinga, Jacco, Eurosurveillance, 25, 2000062 (2020)* [↑](#footnote-ref-7)
8. Kingsland, 2020 [↑](#footnote-ref-8)
9. Heneghan, Brassey and Jefferson, 2020 [↑](#footnote-ref-9)
10. Al-Tawfiq, 2020 [↑](#footnote-ref-10)
11. Roser, Ritchie, Ortiz-Ospina and Hasell, 2020 [↑](#footnote-ref-11)
12. Yong, 2020 [↑](#footnote-ref-12)
13. (Limam, 2020) [↑](#footnote-ref-13)
14. Coronavirus Pandemic Data Explorer, 2020 [↑](#footnote-ref-14)