Efficiency of restrictions used by Denmark and Sweden during the COVID-19 pandemic

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1. Abstract

This thesis aims to analyze and discuss the different approaches and initiatives used by the Swedish and Danish governments in combating the COVID-19 pandemic, as wells as the effect of the arrival of the SARS-CoV-2 B.1.1.7 strain had on the previous set of restrictions and initiatives. The data collected of the total amount of confirmed cases from Denmark and Sweden is used to calculate the R_0 values by using regression analysis on a logarithmic scale. The regression analysis is made for specific time spans after a restriction is introduced. A regression line is fitted to the data from the time span and the slope is used to calculate the basic reproduction number (R_0). The R_0 values are used in the SIR model. The SIR model is used to review the calculated R_0 values by implementing the varying R_0 values to compare and measure the direct effect of the different initiatives.

The SIR model does not predict the exact spread of the virus; however, it is possible to simulate the general tendencies of two waves with the R_0 calculated from the logarithmic plots in the time spans chosen. Furthermore, incidence numbers have been calculated and presented with the restrictions at the selected time spans.

The results show that the lack of data collected in the beginning of the pandemic in Denmark and Sweden makes the comparison of restrictions used by the two countries challenging to analyze for these time spans. The restrictions used by the two countries overlap with multiple restrictions set in motion in the same time spans. This makes it challenging to differ between which of the restrictions that are the most effective. Though by looking at the observed data a combination of the restrictions may have been the most optimal way of reducing further spread of COVID-19 in the population.

The results suggest a correlation between an increased presence of B.1.1.7 and an increase in R_0.

2. Table of content

3. Preface

This bachelor thesis is written by Frederik Bonde Hansen, Nikoline Erland Jensen, Rasmus Balslev Sandvig and Yahya Walid Khalid, bachelor students at Roskilde University.

We would like to thank our supervisor Professor Johnny Ottesen for his counselling during the project. We would also like to thank our opponent group Simon Męski and his supervisor's lector Ole Skovgaard and professor (MSO) Karen Angeliki Krogfelt for constructive feedback at the evaluations. Lastly, we would like to thank Professor Lone Simonsen for ideas, help and materials regarding the thesis

The SIR model analyzed in the project is a modified version of a SEIR model that has been coded by "Kees de Graff", available at https://cs.uwaterloo.ca/~paforsyt/SEIR.html

If the datasheet or modified python code is of interest, please E-mail: nerland@ruc.dk

Vaccines are not being considered in this model, furthermore it has been chosen not to include people who get infected more than once, since the possibility is low, and it does not have an impact on the further course of the pandemic in Denmark and Sweden.

4. Introduction

In December 2019 an influenza like disease emerged from Hunanan Wholesale Marked in the city of Wuhan [1]. The virus spread rapidly and soon to other parts of China. At this point, the Danish Health Authority recommended not to start screening in airports because of the low probability of the virus reaching Denmark. This low probability originated because of the comparison to SARS and MERS that never reached Denmark in any significant way [1].

Fast forward a few months and the epidemic has spread to outside of Chinas borders, and on the 11th of March 2020, it was officially announced as a global pandemic by The World Health Organization (WHO) [2]. As of the 25th of May 2021 3.5 million people have died and 167.3 million people have been infected by SARS-CoV-2 worldwide [3].

There are several strategies used to reduce the spread of COVID-19. Around the world mass-testing, closed public areas, use of face masks, use of hand-sanitation and restrictions to increase social distance are some of the most common initiatives. Restrictions are typically adjusted during the pandemic, tightened when incidence numbers are high, and loosened when low.

This thesis aims to compare Denmark and Sweden due to the different approaches used by the two countries healthcare authorities. Sweden's approach was having few mandatory restrictions, taking a more liberal approach. e.g. recommending the use of face masks on public transport during peak hours, having a smaller than normal social circle and to practice social distancing [4]. While the Danish government took a more authoritarian approach, introducing restriction to stop further spread of COVID-19. These include public gathering bans of more than 5 people, closing liberal professions, malls and closing borders for non-export/import travel.

The arrival of the B.1.1.7 mutation, which is a more infectious strain of SARS-CoV-2 that originated in the United Kingdom, put a greater pressure on the health care systems [5]. This led to new restrictions introduced in the two countries which could play an important role in the reduction of SARS-CoV-2 infections.

If COVID-19 outbreaks are left unchecked, they have the potential to overwhelm the public healthcare system which can lead to an increase in excess mortalities and more lockdowns.

To gain an understanding of the spread of COVID-19 and in general infectious diseases a mathematical compartment model is often utilized. An example of this is the SIR model, which describes the amount of Susceptible, Infected and Recovered in a population, uses data from infected people from previous days to predict future spread. SIR has to parameters which is being used to calculate the basic reproduction number (*R_0*). *R_0* states how many susceptible individuals an infected person on average will infect.

By using the SIR model, the thesis aims to describe the efficiency of restrictions introduced by the Danish and Swedish governments.

4.1. Problem definition / Aim of research

Which restrictions indicate the highest efficiency in containing the spread of SARS-CoV-2 (COVID-19), including the B.1.1.7 strain, according to the SIR model and linear regression analysis based on data from Sweden (Folkhälsomyndigheten) and Denmark (Statens Serum Institut)?

5. Background

This chapter is a short introduction to the ongoing pandemic caused by SARS-CoV-2 and how it has affected both Denmark and Sweden. The chapter includes a detailed explanation of the bio-chemical function of both the novel SARS-CoV-2 and the B.1.1.7 mutation. Furthermore, the chapter includes a description of the biological factors of importance for viral spread. This is done to better describe the strength and weaknesses of SARS-CoV-2, This chapter also includes the different strategies used by Denmark and Sweden. Beside that there is an introduction to the SIR model used in this thesis to investigate which restrictions introduced where the most effective if any.

5.1. General

The virus SARS-CoV-2 is a single-stranded RNA corona virus. The membrane of SARS-CoV-2 is covered with several proteins, here among membrane protein, nucleocapsid protein, spike proteins and envelope protein [6]. The spike protein is of interest because it helps the virus attach to the human host cell [7]. The significance of this protein will be explained in (5.2.2). COVID-19 is a respiratory disease which spreads between individuals via small aerosol water droplets or fomite transmission. The small particles can enter the new host via the nose, mouth and eyes [8].

Transmission of SARS-CoV-2 fluctuates with seasonal change. During the winter months an increase can be observed, due to behavioral changes with people staying more indoors increasing aerosol transmission [9].

Furthermore, super spreader events are crucial for the spread of COVID-19. An effective way to control the spread is to control the number of events where a lot of people are gathered from different parts of the country. If this is controlled then the possibility of COVID-19 spreading further will be lowered [10].

The incubation time of SARS-CoV-2 varies between 1 and 14 days. On average the infected person becomes infectious after 2.5 days [10]. The study by Sneppen, Nielsen, Taylor and Simonsen suggests the infection timeline to be as follows: After contact with an infectious individual a subject is categorized as exposed for 2.5 days. On day 3 after exposure the subject becomes infectious pre-symptomatic for 2.5 days. After the pre-symptomatic stage, the subject enters the infectious symptomatic stage and stays there for 3 days. From the infectious symptomatic stage, the subject enters the symptomatic non-infectious stage for 2 days before entering the recovered stage. Thus, the infectious stages spans over a total of 5.5 days, and a total infected period spans over a total of 10 days (Figure 1) [10].

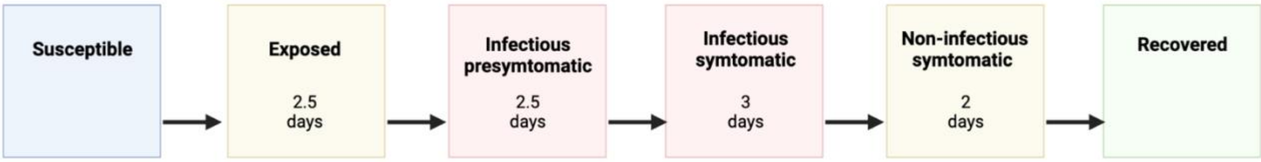


Figure 1 The figure describes the stages an individual goes through from being susceptible to being recovered. Between these stages the infected individual goes through four other stages; Exposed, Infectious presymptomatic, infectious symptomatic and non-infectious symptomatic [10]. *Modified with www.biorender.com..*

5.2. SARS-CoV-2

Serve Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) is a zoonose virus. SARS-CoV-2 has a genome length of about 30,000 nucleotides. The mutation rate of this genome is estimated to be approximately 10^{-6} substitutions pr site pr replication cycle [11]. This mutation rate is lower than what is observed in the common influenza which has a mutation rate of approximately $3x10^{-5}$ substitutions pr site pr replication cycle [11]. By taking a closer look at the SARS-CoV-2 genome sequence from Wuhan, China it is observed that all known mutations in the genome occur in the nucleotide sequence, that does not code for proteins which are critical for the survival of SARS-CoV-2. Meaning that the mutations have both negative and positive effects on the virus, but few of the mutations make SARS-CoV-2 more efficient when it comes to infecting more people [12].

The rate of mutations observed in single stranded RNA virus are larger than of what is seen in prokaryotes and eukaryotes. RNA based viruses like SARS-CoV-2 has a fast replication rate which this increases the probability of errors in the replication state. The lockdown procedures set in action by the Danish and Swedish governments are set in motion to minimize the number of infections. However, it is also critical to lower the number of infections in the population creating a bottleneck effect of the total virus gene pool of SARS-CoV-2. By lowering the population of infected individuals, the rate of mutations are also lowered [13].

5.2.1 Novel SARS-CoV-2

The genome of the novel SARS-CoV-2 belongs to the beta-coronavirus (β-CoV) family. This family comprises of an enveloped, non-segmented, positive sense single-stranded RNA virus genome, with a 5' cap structure and 3' poly-A tail. This allows it to perform as mRNA for translation of the replicase polyproteins [12]. The genome of β-CoVs encodes for several non-structural and four structural proteins, including spike (S), envelope (E), membrane (M) and nucleocapsid (N) (**Error! Reference source not found.**) [13].

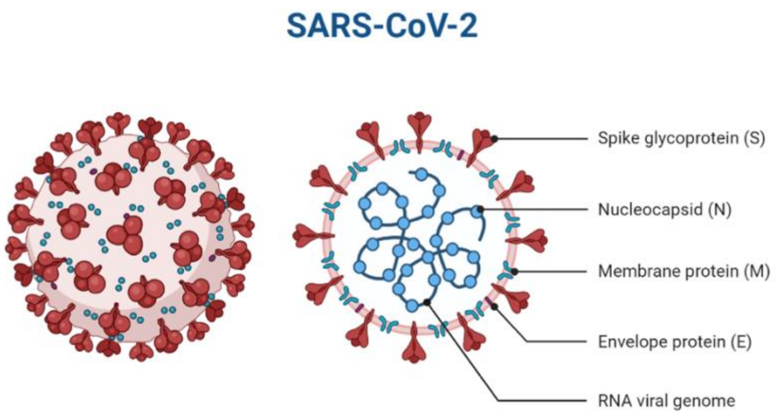


Figure 2 The figure shows the structure of the SARS-CoV-2 virus. The diagram shows spike glycoproteins (S), nucleocapsids (N), membrane proteins (M), envelope proteins (E) and the RNA viral genome. Modified in www.biorender.com.

The genome varies in size from 29.8 kb to 29.9 kb [14] and its genome follows the specific gene characteristics known to CoVs. The spike protein is composed of glycoproteins and protrudes from the lipid bilayer that surrounds an enveloped virion. Spike proteins play an importin role in the release of SARS-CoV-2's nucleocapsid into the host cell cytoplasm by attaching to the angiotensin-converting enzyme 2 (ACE2) receptor site and ensures fusion between the host membrane and envelope of the virion [15]. The most common types of mutations in SARS-CoV-2 genomes are missense and synonymous mutations [16]. Genetic diversity is critical for the fitness, survival and probably the pathogenesis of SARS-CoV-2. A study has shown that random mutations and recombination are two of the main sources for genetic diversity in this virus. Nine presumed recombinant patterns were identified in the SARS-CoV-2 genome, including six critical recombination regions of the spike protein gene (S gene) [17].

SARS-CoV-2 mutations have been reported in several genes. The S gene along with several open reading frame (ORF) and non-structural protein (nsp) genes show remarkably more mutations than other genes. Of these mutations neutral hydrophobic changes occurred more in the S protein than the other genes meaning that the water accumulation in the cell rises [18]. The hydrophobic change affects the affinity of the spike protein to the ACE2 binding site, thus changing the infectiousness of SARS-CoV-2 [19]. A combination of mutations in the S gene led to the B.1.1.7 strain.

5.2.2. SARS-CoV-2 strain B.1.1.7

By looking at the B.1.1.7 SARS-CoV-2 linage, it is observed that there are critical mutations in the spike proteins. This makes B.1.1.7 spread more efficiently than the previous dominating mutation (linage A) [14]. Looking at statistics from The United Kingdom, it is observed that the B.1.1.7 is out competing the previously dominating strain [15]. This shows how critical it is to track and sequence different mutations during SARS-CoV-2 testing. Similar effect is observed in both Danish and Swedish statistics [16][17].

The mutations typically occur in the part of the SARS-CoV-2 genome that is not critical for the function of SARS-CoV-2 [18].

The most critical mutation in the B.1.1.7 linage is in the receptor binding protein (RBD). Here an amino acid change has led to increased binding between the spike proteins and ACE2 thus leading to the B.1.1.7 lineage binding more efficiently to the human cell, making it more infectious. B.1.1.7 has 23 mutations when compared to the original SARS-CoV-2 strain from Wuhan. The most significant mutations in B.1.1.7 are, N501Y and 69-70del. The changes in the RBD sequence are nonsynonymous where an amino acid change has occurred (asparagine to tyrosine) in position 501 in the spike protein [19].

When looking at the mutations of interest in B.1.1.7 it is observed that SARS-CoV-2 is adapting to the human immune system, in a way that may be concerning for the production and viability of current vaccinations. The 69-70del mutation has resulted in deletion of two amino acid in the spike protein. This change may lead to the human antibodies not recognizing B.1.1.7, thus making it a challenge for the immune system to delay or overcome the B.1.1.7 lineage of SARS-CoV-2 on its own. This mutation may lead to difficulties when treating patient with immune therapy [7].

5.3. Observed data from Denmark and Sweden

To define the difference in the total number of observed tested and infected individuals in Denmark and Sweden a comparison of these has been made. By doing this it becomes possible to see the differences during the span of the pandemic.

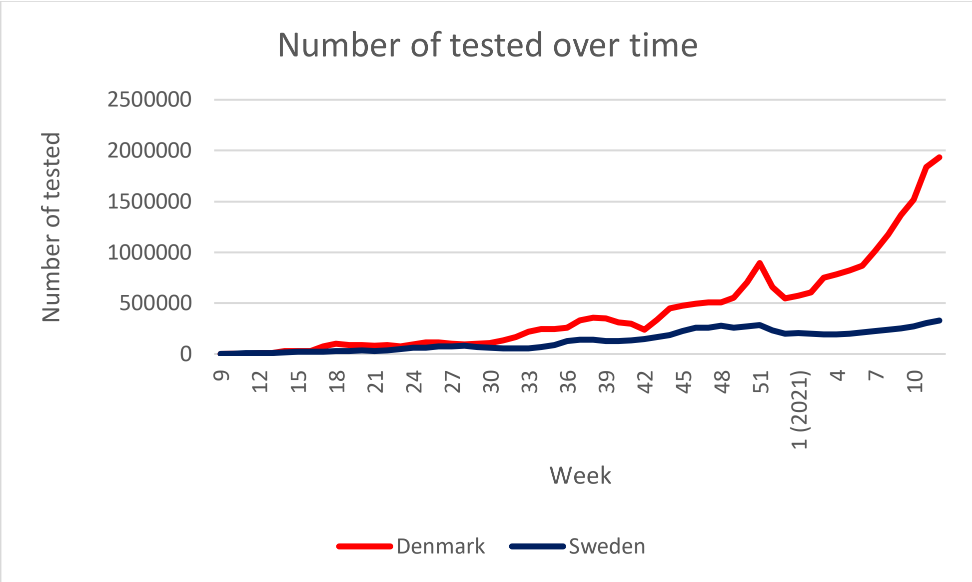


Figure 3 The figure has number of PCR test on the Y-axis and week number on the X-axis. The figure shows gross number of people tested each week with a PCR test in a time span from week 9 2020 to week 12 2021. Denmark is represented by the red line and Sweden is represented by the blue line. Data from SSI [20][21] *and Folkhälsomyndigheten [22.]*

Denmark ramped up its testing capacity from the start of the pandemic reaching 1,934,050 weekly PCR tests by week 12 [20]. Sweden also ramped up its testing capacity, though not as significantly reaching 329,080 weekly PCR tests in week 12 [21]. The two countries perform around the same amount of PCR tests until week 42. Denmark's PCR test capacity increased significantly from around Christmas until week 12, while Sweden test capacity has remained stable in the same time span (Figure 3)[20][21].

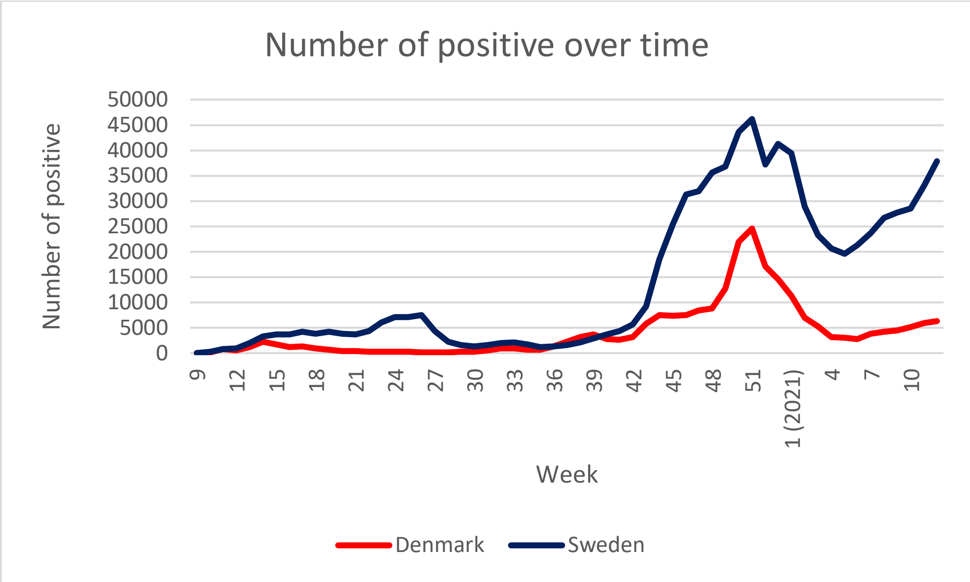


Figure 4 The figure has number of positive PCR tests on the Y-axis and week number on the X-axis The figure shows number of positive PCR tests each week in the time span week 9 2020 to week 12 2021. Denmark is represented by the red line and Sweden is represented by the blue line. Data from SSI [20][21] *and Folkhälsomyndigheten* [21].

Denmark and Sweden followed similar trajectories from week 9 to week 14 during the first wave of COVID-19. Sweden had more confirmed positive PCR tests in week 15-29. Between week 30 and 42 both countries have a similar number of positive PCR tests, both increasing. Around week 42 the second wave of COVID-19 starts. Here both Denmark and Sweden experience similar tendencies with an increase in positive PCR test. The second wave lasts till around Christmas where a decrease follows. From week 6 to week 12 both countries have an increase in positive PCR test, though Sweden's increase is more significant (Figure 4) [20][21].

5.4. Biological factors important for viral spread

SARS-CoV-2 particles requires a host to spread between individuals. SARS-CoV-2 induces coughing and sneezing which are vital for its spread. By aerosols it transmits in small mucus or water droplets from one host to another through the air [8]. The biggest viral load is observed to be in the upper respiratory tract e.g., nasopharynx and oropharynx [22]. Thus, coughing and sneezing is a direct pathway for COVID-19 to spread between individuals in a population. Studies have also shown a small chance of fomite transmission while the dominant way of transmission being respiratory [8], [22]. To prevent this respiratory transmission there are several restrictions and advises that can be followed by the general population. By coughing and sneezing into the sleeve both fomite and direct respiratory transmission is reduced due to some of the droplets being blocked [23]. Some mucus and water particles are caught in the elbow consequently not reaching a new host. A way to improve this concept is by using facemask. Facemask has a grid-like structure in its fabric. The pores in the fabric are small enough to allow air to pass through, however they are small enough to catch the aerosols [24]. Face masks has to be utilized correctly to have a proven effect on reducing the spread of respiratory diseases [25]. Not using hand-sanitation after each use or after touching the mask is considered incorrect use because it can cause fomite transmission [24].

Another way of reducing the direct airway transmission is to increase the distance between individuals. Aerosol water droplets coughed by an infected individual travels 1.5-3 meters. Where for an individual wearing a disposable mask, cough droplets only travel 6.35 to 20 cm meters [26][27]. If a suspectable individual is located within the coughing distance and is exposed to these particles the individual may get infected. By increasing the distance between people in shopping malls, restaurants, and other social and public settings the transmission rate is reduced [28]. Having reduced work place attendance and closed schools also reduce the transmission rate as it decreases the amount individuals each person physically interacts with [28]. By closing professions that require close contact like hairdressers and restaurants it is possible to minimize the risk of further transmission [29].

To limit the rate of mutations of SARS-CoV-2 and the global spread, it might be necessary to close borders. When the borders are closed, the population is isolated from other countries. This ensures that new mutations from other countries does not enters the population. [30].

Mass-testing of the populations gives an overview of how many individuals in a population is infected. Rapid knowledge of whether an individual is infected leads to quicker isolation that lowers the infection rate and if done nationally lowers the R_0 value. By knowing the exact number of individuals that are infected, it is possible to adapt the restrictions set into place at the current moment [31].

5.3.1. COVID-19 restrictions in Denmark and Sweden

During the pandemic several restrictions has been introduced in Denmark and Sweden.

Denmark experienced its first confirmed case of COVID-19 on the 27th of February 2020 (Figure 5). The first confirmed case in Sweden was almost a month prior on the 31st of January 2020 (Figure 6). While the two countries have many similarities, they chose to deal with the pandemic with different restrictions (11.1, 11.2)

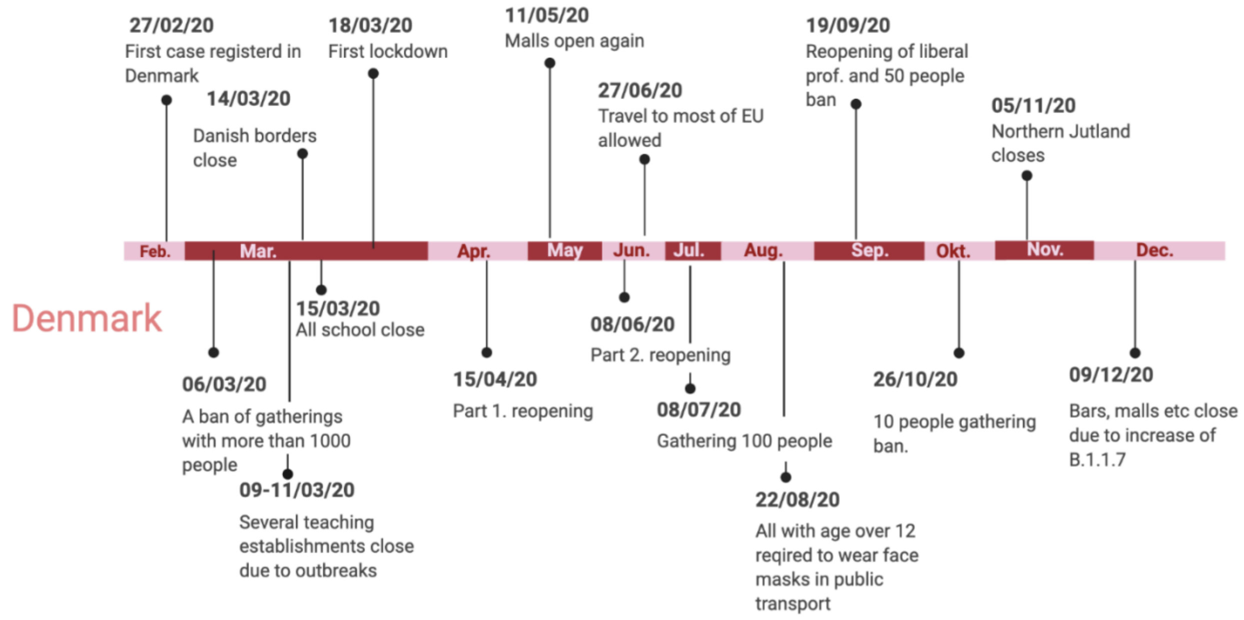


Figure 5 The figure shows a chronological timeline of the key restrictions in Denmark during the COVID-19 pandemic. Modified with www.biorender.com. Please note that the distance between points is not made to scale.

Denmark prohibited all events exceeding 1000 participants on the 6th of March 2020 two days after the first 15 cases confirmed (Figure 5). On the 18th of March 2020 Denmark enters lockdown with all liberal professions being forced to shut down. At this time 1044 people had tested positive for SARS-CoV-2 in Denmark [32].

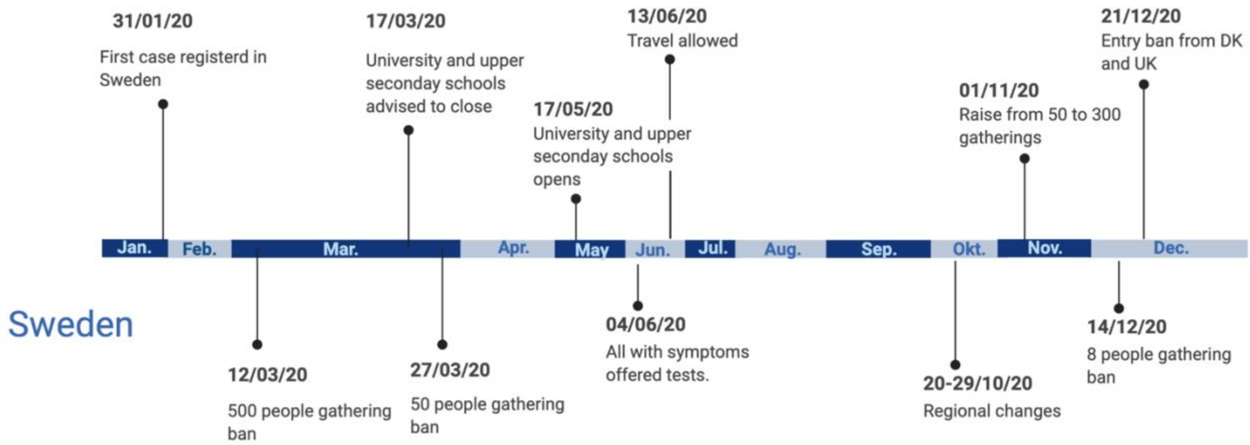


Figure 6 The figure shows a chronological timeline of the key restrictions in Sweden during the COVID-19 pandemic. Modified with www.biorender.com. Please note that the distance between points is not made to scale.

In comparison Sweden prohibits gatherings of over 500 people on the 12th of March 2020. Five days later, on the 17th of March 2020 it was advised for university and upper secondary schools to do online teaching, also all non-essential travel to non-EU countries were advised against (Figure 6). Sweden had 1265 confirmed cases at this time. Sweden never entered a full lockdown but on the 27th of March 2020 Sweden prohibited gatherings of more than 50 people (Figure 6).

During the spring and summer (the 15th of April 2020 to the 08th of July 2020) Denmark reopens for the first time due to a low infection rate (Figure 5). First primary schools opened, then liberal professions were opened and outdoor sports activities. Around a month later malls were opening together with middle schools, bars, and restaurants, though bars and restaurants must close before midnight. Amusement parks opened together with indoor sport activities. Here the gathering of people was raised to 50. Lastly borders opened to all countries except Sweden and Portugal and gatherings of up to 100 people were allowed.

Denmark made it mandatory to wear face masks in public transport on the 22nd of August 2020. Sweden also lightened the restrictions from the 29th of May 2020 to the 1st of November 2020. First upper secondary schools and universities opened, then all domestic travel was opened but under the requirement of social distancing. More than two months later assemblies of up to 500 people were allowed. From the 20th to the 29th of October 2020 more regional recommendation were set in motion. In Skåne, Uppsala, and Stockholm people were recommended to avoid restaurants, fitness centers, malls, and public transport. All though these regions had tighter recommendations, the general restrictions had a raise in people being seated at social gathering. This was raised from 50 to 300.

On the 26th of October 2020 Denmark prohibited gatherings of more than 10 people. On the 9th of December 2020 bars, malls etc. were closed due to a surge in COVID-19 cases. Later an increased threat from the B.1.1.7 mutation which accounted for 0.8% of sequenced samples became evident on November 16th to December 27th 2020 [33].

5.5. SIR model

The Susceptible-Infected-Recovered model (SIR model) is an epidemic or pandemic mathematical model built up by three coupled differential equations. The SIR model is used to explain how a disease develops in a population over time. It contains three compartments, which represents the various conditions of susceptible, infected, and recovered individuals during an epidemic or pandemic breakout.

The different compartments seen in the SIR model is the susceptible (*S*), infected (*I*) and recovered (*R*) (Figure 7) [34].

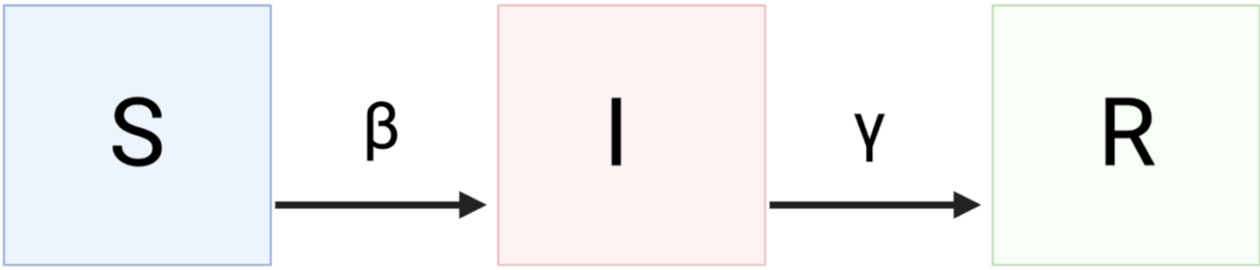


Figure 7 This figure shows the compartments and parameters of the SIR model. Compartments: S=susceptible, I=Infected, R=recovered (immune or dead). Parameters: β= infection rate (rate of which individuals moves from S to I) and γ=number of days from infected until recovered/death (time where individuals move from I to R) [34]. *The figure is made in www.biorender.com.*

The susceptible (*S*) part of the population can potentially be subjected to infection. At initial time this compartment represents almost the entire population. The infected (*I*) represents the population that is infected. Lastly the recovered (*R*) part are the people that have become immune or have died. This means that people in the *R* compartment cannot be reintroduced in the system [35].

The compartment model can be considered as a closed dynamical system, where people move from one compartment to the other. Therefore, a characteristic of this model is that the sum of the three categories is equal to the total population (*N*) at any time ignoring births, migration, immigration, and deaths not caused by the disease, as seen in equation (1).

$$S + I + R = N \tag{1}$$

Throughout the model the population in the *S* compartment decreases over time (*t*), feeding into the *I* compartment. The opposite is true for the *R* compartment [36]. In the model *t* is constant with days.

$$\frac{dS}{dt} = -\beta \cdot I \frac{S}{N} \tag{2}$$

$$\frac{dI}{dt} = \beta \cdot I \frac{S}{N} - \gamma \cdot I \tag{3}$$

$$\frac{dR}{dt} = \gamma \cdot I \tag{4}$$

Beta *(β)* is decreasing in equation (2) feeding into equation (3) and is therefore moving people from the *(S)* to the *(I)* compartment. In equation (3) gamma *(γ)* decreases and feeds into equation (4) and is therefore moving people from the *(I)* to the *(R)* compartment.

In the three equations there are two variables γ and β. The γ parameter is the recovery rate or death rate [37]. This parameter is defined by exponential decay and explains the average time it takes for people to recover or die from the disease. By changing the γ parameter the growth rate of R compartments will be affected. Since γ is the average amount of time it takes an individual to move from I to R, it is constant [34].

The β parameter, which is called the infection rate, controls the rate of which the population in the susceptible compartment decreases over time. Therefore, β tells a what probability a susceptible is getting infected from an infected. The infection rate is further multiplied by the ratio $\frac{S}{N}$ (The probability of a random person being susceptible). The rate of which the population will move from the S compartment to the I compartment will increase if β is increased. A disease with a high β is more efficient in infecting people and therefore spreads faster in the population. By changing the β parameter the infectious rate will either increase or decrease [34]. The changes in β will affect the outcome of R_0. The reproduction rate (R_0) describes the average of how many persons an infected person infects with the disease, as seen in equation (5). R_0 is defined by the two parameters β and γ. Therefore, β affects R_0 because R_0 is the ratio between β and γ (5) [38].

$$R_0 = \frac{\beta}{\gamma} \tag{5}$$

If R_0 is less than one, the disease will slowly die out to a point where it will not be an important factor in the population. If R_0 is greater than one, the disease will spread in the population. If R_0 is one, then the spread of the disease will be in a steady state [37].

In the SIR model R_0 is usually constant, but in this thesis R_0 will not be constant due effect of the government's restrictions and lockdowns.

Table 1 The table shows the different compartments and parameters of the SIR model.

S	The number of people susceptible on day (t)
I	The number of people infected on day (t)
R	The number of people recovered or dead after (t) days
N	The total population
β	Infectious rate (t^{-1})
γ	The average length a person is infected (t^{-1})
R_0	The total number of people an infected person can infect

In mathematical modeling of a disease like COVID-19 it is critical to understand how COVID-19 is behaving in a population and if the additional restrictions are beneficial or if further restrictions are required. The SIR model is simple, although compartments can be added to make the model more complex. By adding more parameters and variables the model can produce a more realistic result of e.g., the current COVID-19 pandemic. The SIR model is used to give an indication of how the pandemic will develop over time [39]. The SIR model can be changed, and compartments can be added or removed to make the model fit most infectious diseases. When looking at few parameters the basic SIR model will describe what this thesis is researching. This will be presented in chapter (6). Because of the simple version of the SIR model, it has a few limitations e.g., it assumes that everybody will meet and infect each other in the population.

6. Methods and data

This section aims to specify the SIR model. The model is described in detail in the theory chapter on SIR models, where the specific setup is explained. The SIR model has been coded in python. Furthermore, a short description on how the data is being treated and implemented is described in this chapter.

6.1. Timeline on Danish and Swedish COVID-19 initiatives

The timelines constructed are based on official government initiatives from Denmark and Sweden, where the individual restrictions chosen are on restrictions and recommendations from the governments. The Swedish timeline (11.1) and the Danish timeline (11.2) are constructed to give an overview of the implemented initiatives against COVID-19. The Swedish timeline is constructed from the Swedish health authority, Folkhälsomyndigheten's webpage and the Swedish webpage for emergency information from the Swedish authorities, krisisinformation.se [4], [40]. The Danish timeline is constructed from the Danish health authority's webpage coronasmitte.dk, from the government's webpage regeringen.dk and from the Danish ministry of health, Sundhedsministeriet's webpage [41]–[44]. The timelines are further backed by the SIR model, to show which restrictions have had the biggest impact on the spread of COVID-19. Furthermore, the implications of the timeline in the SIR model will only make use of restrictions and lockdowns, and not recommendations from the governments. This is chosen because it will yield a better understanding on how effective the introduced initiatives have on the spread and containment of COVID-19 in Denmark and Sweden.

The Danish timeline which makes the base of the different time spans used in the SIR model has initiatives that has not been used, since they are not of interest in this thesis. The timeline is divided in 11 restrictions and 7 reopening initiatives.
The first restriction was introduced on the 6th of March 2020 and was a ban on gatherings of more than 1000 people.
The next restriction was introduced on the 14th of March 2020, which was closing the Danish borders, furthermore the nationwide lockdown was introduced on the 18th of March 2020. Denmark was closed in this time span, all employees with non-critical work was advised to work from home. Denmark stayed in lockdown until the first part of the reopening which was introduced on the 15th of April 2020. On the 8th of June 2020 the second part of the reopening was announced and on the 27th of June

furthermore on the 8th of July 2020 gatherings of 100 people was now allowed again. On the 22nd of August it was now required to wear a facemask when traveling with public transportation.
On the 19th of September it was announced that it was required to wear a face mask or visor at restaurants, cafés, and bars. Furthermore restaurants, cafés, and bars were told to close at 10pm all over the country and gatherings of a maximum of 50 was set in place.
On the 26th of October gatherings of more than 10 persons was not allowed. On the 5th of November 2020, seven municipalities in northern Jutland got special COVID-19 restrictions, due to a COVID-19 mutation spreading among minks. People were recommended not to travel outside their own municipality and students from 5-8th grade were online schooled. Restaurants, gyms, and cinemas were closing, and it was not possible to use public transportation between the seven municipalities until the 3rd of December 2020. On the 9th of December 2020 further restrictions had their onset, 5th grade and up were being online schooled. Restaurants, bars, cinemas, and theaters were closing until the 3rd of January 2021. These restrictions included 38 municipalities including Copenhagen, Aarhus, and Odense. On the 17th of December 2020 it was decided to close malls, restaurants, and cafés. On the 25th of December 2020 Denmark got into the second lockdown. This time all stores except supermarkets and pharmacies were closed. All students were now being schooled online.
From the 5th of January it was only allowed to be in gatherings of 5 persons in public. Denmark began to open again on the 8th of February where 0-4th grade were allowed back in school. Furthermore, on the 1st of March 2021 outdoor sports activities were opening at a 25 people maximum capacity. Zoos and amusement parks were allowed to open though a negative COVID-19 test was required. Smaller stores that were not located in malls were allowed to open. On the 15th of March 2021 boarding school and folk high schools were allowed back. 5-8th grade students were allowed once a week for physical school outdoors. All 9th and 10th grade students were back in school excepts in arears around Copenhagen. On islands not connected by bridge to mainland Denmark all students were allowed back on full time.

The Swedish timeline which makes the base of the different time spans used in the SIR model has initiatives that has not been used, since they are not of interest in this thesis. The timeline is divided in 4 restrictions, 2 reopening initiatives and 1 with no restrictions or initiatives set in place which represent an uncontrolled spread.
Sweden introduced the first restriction starting from the 12th of March 2020 with a ban of social gatherings exceeding 500 people. During the same week all non-essential travel and physical school

was advised against. The social gathering ban was changed a couple of weeks later as of the 27th of March 2020 socials gatherings could not exceed 50 people.

The 29th of May upper secondary schools and universities were allowed to open again and do physical teachings. The Swedish government follows a recommendation made by the Swedish health authorities on the 27th of August and raise the amount of people allowed to gather from 50 to 300 individuals on the 1st of November 2020. On the 3rd of November, two days after the raise, the Swedish government bans more than eight people in seated groups at restaurants and bars, and the 16th of November the ban is recommended to apply for all public areas. The 14th of December the 2020 this recommendation was made a ban and four days later the 18th of December the eight people social gathering ban was lowered to four people per seating at restaurants and bars. The B.1.1.7 mutation starts to spread around Europe during December of 2020 and as response the Swedish government prohibits entry from Denmark and the United Kingdom starting from the 21st of December 2020. Norway confirmed B.1.1.7 strain incidences during January of 2021 which Sweden responded to by establishing an entry ban from Norway to Sweden the 24th of January 2021.

6.2. Implementation of data from Denmark and Sweden

Denmark and Sweden deployed different strategies to track COVID-19. The Danish data is reported daily, while Swedish is reported weekly. The difference in the collection of data from Denmark and Sweden complicates the fitting and implementation of data in the SIR model and creates uncertainties. The data that is being collected in the two countries is based on the number of SARS-CoV-2 tests made. The data that is used in this thesis is therefore reliant on the test capacity in the two countries and is only based on confirmed cases.

The number of confirmed cases / infected individual can be used in the SIR model as the I compartment represent the confirmed cases at a given time. Although it is difficult to say when an infected moves to the R compartment based on the data alone.

Data on the Danish confirmed cases are found on Statens Serum Institut's (SSI) webpage, where it is published [20].

In Denmark, the government is responsible for collecting data and publishes a daily report. The data used in this thesis is downloaded on the 31st of March 2021 and includes data until the 30th of March 2021. The Danish data is published in cases per day and will be handled with cases per day throughout the data processing. Furthermore, the Danish data comes from two different files, because Denmark publishes PCR- and Antigen-tests separately. The antigen-test has been recorded since the 1st of January 2021. In the data sheet PCR-test and antigen-test are merged. Data from Denmark is being processed from the 2nd of March 2020 until the 28th of March 2021.

Data on the Swedish positive cases are found on Folkhälsomyndigheten's webpage [21].

In Sweden the regions are accountable for data collection which is being published on weekly basis and with cases per week due to this data is being handled differently from the Danish. This is done to get the most accurate results, since more datapoint equals less uncertainties. The Swedish data is downloaded on the 1st of April 2021 and holds data until week 12 of 2021.

In the data sheets from Denmark and Sweden incidence numbers have been calculated to make data from two countries more comparable.

Sweden has almost double the number of citizens compared to Denmark, therefore incidence numbers has been made to compare the Danish and Swedish gross infected numbers. To calculate the incidence the Danish data has been summarized into weeks, because the Swedish data is given in weeks. The incidence number has been calculated by equation (6):

$$Incidence = \frac{Infected_{week}}{Population} \cdot 100{,}000 \tag{6}$$

This gives an infected pr. 100,000 citizens ratio for each week.

Calculations of R_0 has been made here as well.

The R_0 values has been calculated from plots where the logarithm has been taken from the number of infected, either per day in Denmark or per week in Sweden. The R_0 values are calculated based on the different initiatives introduced in the two countries and are divided into different time spans.

It is possible to calculate R_0 from logarithmic plots by using the slope of the trend line and γ as seen in equation (7).

$$R_0 = \frac{slope + \gamma}{\gamma} \tag{7}$$

It can be derived that the slope of the logarithmic plot together with the average length of infection can describe the infection rate (8). This tells about the rate at which a susceptible becomes infected.

$$slope + \gamma = \beta \quad (8)$$

From this it is seen that the product of reproduction rate and average length of infection is also equal to the infection rate. (9).

$$R_0 \cdot \gamma = \beta \quad (9)$$

This means that the difference between the rate of infection and the average length of infection is equal to the slope of the plots.

$$\beta - \gamma = slope \quad (10)$$

These R_0 values are calculated to see if an initiative has had an influence on the spread of COVID-19. The values are also used to determine β in the SIR model and are therefore crucial for the model.

When implementing the preventive and reactionary initiatives in the model 14 days are being added when looking at the effect of an initiative. This is done because there is a delay in when it is possible to see an effect of an initiative and when its put into effect [45]. Even though this has been taken as a precaution to make data more reliable, there is still a large dark number in the beginning of the pandemic.

In Denmark the testing strategy has changed over time. In the beginning of the pandemic only people with severe symptoms got tested, all other with symptoms were told to self-isolate for two weeks. As the country started opening after the first lockdown more and more people with symptoms got tested [46]. As of August 2020, most people started getting tested on a more weekly basis or at least if they had larger events to attend to. In January 2021 most workplaces with people that were not sent home were encouraged to get tested once or twice a week [46]. This has influenced the number of new cases, since more asymptomatic people are getting detected. Contact tracing has also influenced the number of tests. As of May 2021, around 175,000 PCR-tests and 350,000 antigen tests are made daily [20].

In Sweden testing mainly focused on hospitalized patient with severe COVID-19 symptoms in the beginning of the pandemic. In the following months mostly hospitalized patient and healthcare workers got tested, and therefore not people with mild or no symptoms [47]. In June 2020 the testing strategy changed and now included mass-testing of individual with COVID-19 symptoms. As of November 2020, around 250,000 tests were performed weekly. Since February 2021 the testing capacity has steadily improved, and now between 200,000 and 250,000 PRC-tests and around 30,000 antigen tests are performed each week. The 2nd of March 2021 Sweden started contact tracing in workplaces [48].

The lack in testing symptomatic individual in the beginning also gives Sweden a large dark number. The change in testing strategies makes some parts of the dataset less reliable than other, especially data from the first part of the pandemic is deficient.

6.3. Model setup for SIR model

The parameters in the SIR model are usually constant. In this case, it has been decided to use a γ value of $\frac{1}{10}$, due to the unit of γ which is t^{-1}. The γ value chosen is based on a study done by Sneppen, Nielsen, Taylor and Simonsen [10]. Even though there is an incubation period connected to SARS-CoV-2, it has been chosen that that the incubation- and infectious period should be merged in the *I* compartment. This is done due to a doubt in incubation time and when disease transmission begins in the incubation period. The other parameter of the SIR model β is usually constant.

In this thesis β will not be estimated in the model because it can be calculated from the values γ and R_0, $\beta = R_0 \cdot \gamma$.

As mentioned in the chapter (6.2). R_0 has been calculated from logarithmic plots based on daily from Denmark or weekly cases from Sweden of COVID-19. Therefore, the R_0 value will be changed throughout the model according to the time spans making it dynamic. The focus in this thesis is to try to determine how the restrictions influence the spread of COVID-19. Therefore, it has been decided to calculate the R_0 values from the time spans of the different initiatives made by the Governments.

The R_0 values has been adjusted to 1.7 in Sweden [49] if values were higher than that and the initial number of infected has been set to 60 [50]. For the Swedish model R_0 has been set to change seven times throughout the run according to the seven calculated R_0 values from the different time spans. The model was run for 399 days.

The same adjustment has been made in Denmark if values were above 2.5 [51]. The initial number of infected has been set to 175 in Denmark and the susceptible has been set to the represent the total Danish population. Furthermore, the Danish model changes R_0 17 times throughout the 392 days the model has been run.

Values have been adjusted to found initial values to make the output of the SIR model more reliable.

7. Results and analysis

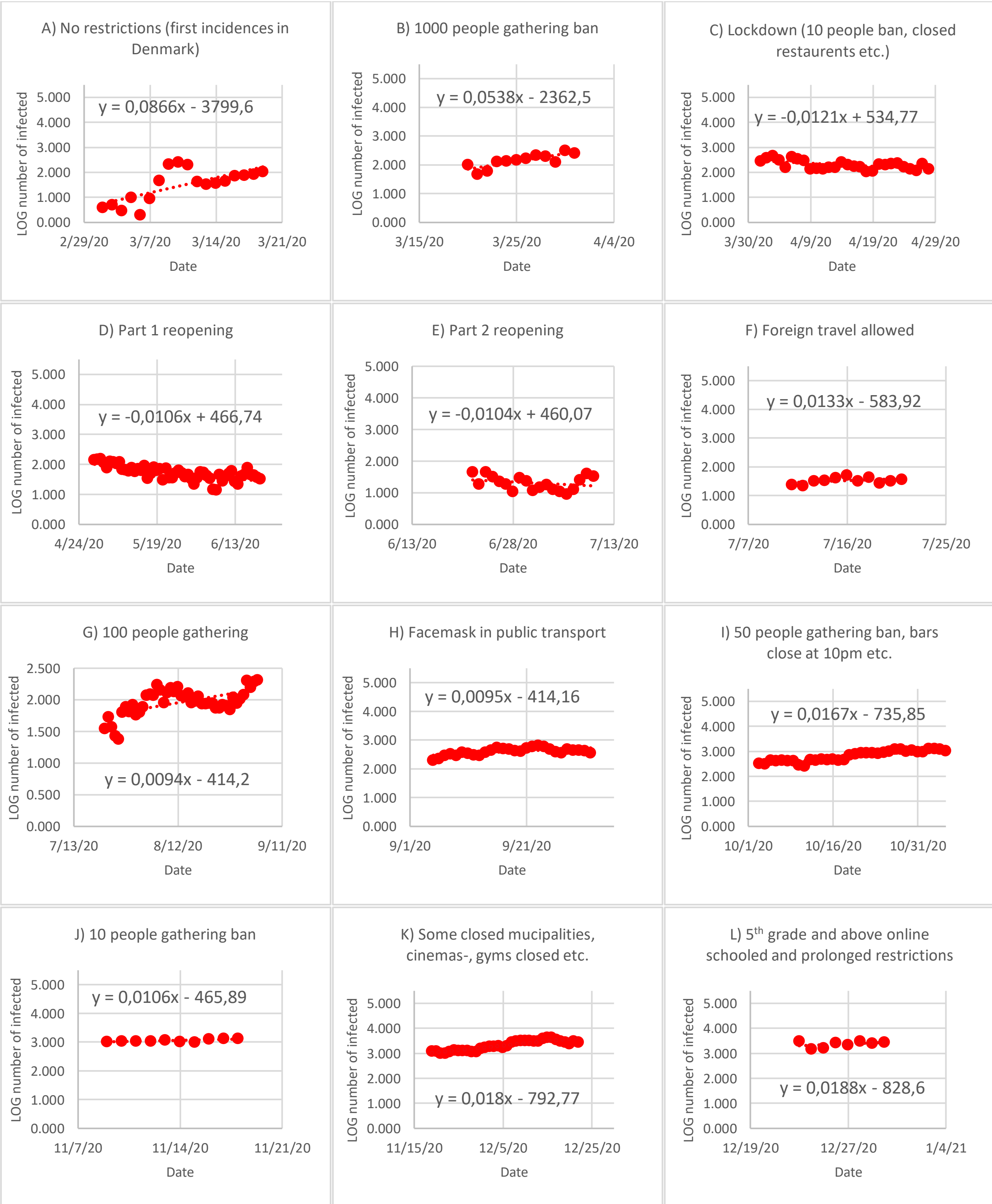
This section aims to analyze the collected data from the Danish SSI and the Swedish Folkhälsomyndigheten. Logarithmic plots of the data have been produced in order to calculate the R_0 values. This have been done for both the Danish and Swedish data. The calculated R_0 values from the logarithmic plots are then used in a SIR model to and evaluate the calculated numbers. Finally, incidence numbers from the two countries have been made and are presented along with the restrictions and initiatives used by Sweden and Denmark.

7.1. Presentation of logarithmic plots and R_0 values

To compare the different restrictions between Denmark and Sweden the data of newly infected from these countries has been split into the chosen time spans. The data in these time spans is put into logarithmic plots and a trendline is added, furthermore the slope of the trendline was added to each plot.

7.1.1. Danish logarithmic plots and R_0 values

The Danish data from the first case of COVID-19 the 3rd of March 2020 to the 28th of March 2021 have been split into 17 different time spans. The time spans show the general trend after the introduction of restrictions that were put into motion by the Danish government. This includes restrictions that are likely to influence the COVID-19 spread. Note that the length of the time spans varies and the trendline does not necessarily fit the data very well, however it indicates whether the infection rate is increasing or decreasing.


A) No restrictions (first incidences in Denmark)
y = 0,0866x - 3799,6
LOG number of infected
5.000
4.000
3.000
2.000
1.000
0.000
2/29/20
3/7/20
3/14/20
3/21/20
Date
B) 1000 people gathering ban
y = 0,0538x - 2362,5
LOG number of infected
3/15/20
3/25/20
4/4/20
Date
C) Lockdown (10 people ban, closed restaurents etc.)
y = -0,0121x + 534,77
LOG number of infected
3/30/20
4/9/20
4/19/20
4/29/20
Date
D) Part 1 reopening
y = -0,0106x + 466,74
LOG number of infected
4/24/20
5/19/20
6/13/20
Date
E) Part 2 reopening
y = -0,0104x + 460,07
LOG number of infected
6/13/20
6/28/20
7/13/20
Date
F) Foreign travel allowed
y = 0,0133x - 583,92
LOG number of infected
7/7/20
7/16/20
7/25/20
Date
G) 100 people gathering
y = 0,0094x - 414,2
LOG number of infected
2.500
2.000
1.500
1.000
0.500
0.000
7/13/20
8/12/20
9/11/20
Date
H) Facemask in public transport
y = 0,0095x - 414,16
LOG number of infected
9/1/20
9/21/20
Date
I) 50 people gathering ban, bars close at 10pm etc.
y = 0,0167x - 735,85
LOG number of infected
10/1/20
10/16/20
10/31/20
Date
J) 10 people gathering ban
y = 0,0106x - 465,89
LOG number of infected
11/7/20
11/14/20
11/21/20
Date
K) Some closed mucipalities, cinemas-, gyms closed etc.
y = 0,018x - 792,77
LOG number of infected
11/15/20
12/5/20
12/25/20
Date
L) 5th grade and above online schooled and prolonged restrictions
y = 0,0188x - 828,6
LOG number of infected
12/19/20
12/27/20
1/4/21
Date

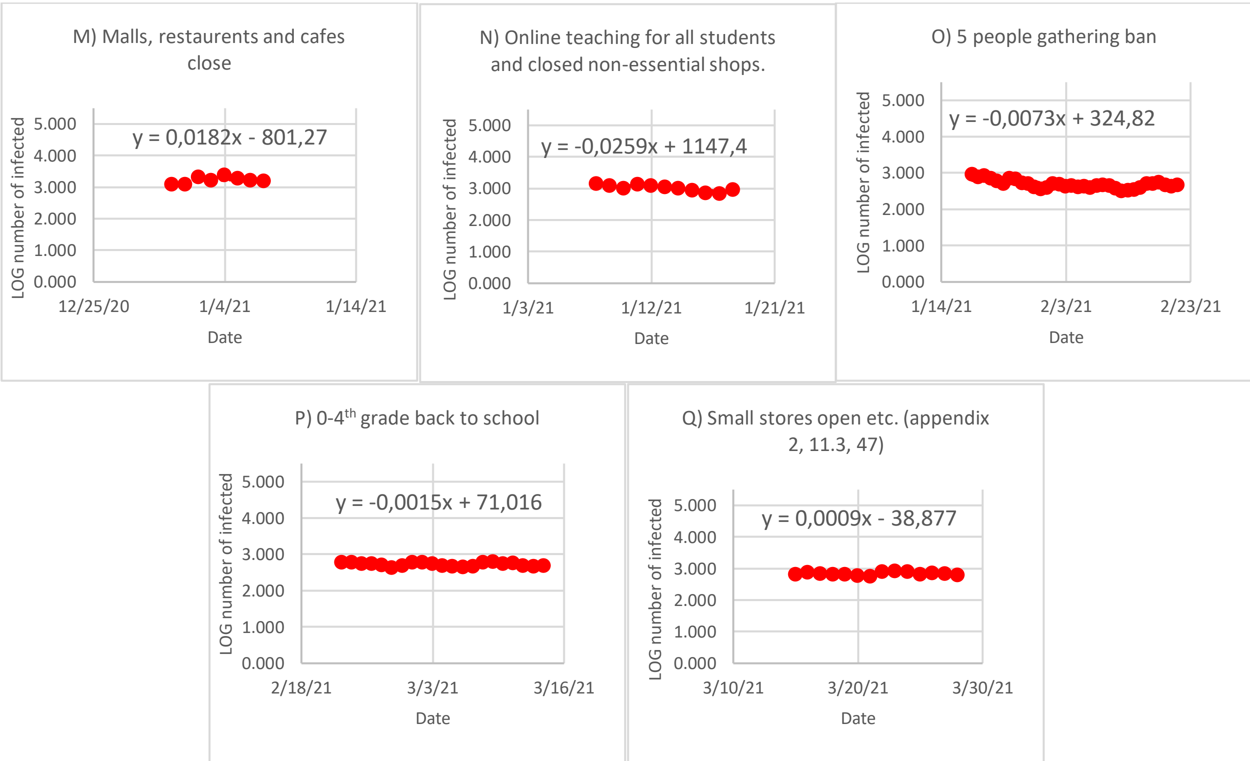


Figure 8 The logarithmic plot is created with the Danish data from SSI from different timespans. The X-axis represents the date of observed infections, and the Y-axis represents log values of observed infected individuals. The logarithmic values from the observed data set are plotted from each day. A trend line was added to determine the slope from the time interval between restrictions to obtain as accurate a value as possible. The slope of the trend line is used to calculate R_0. This has been done for each timespan following a new restriction being put into effect.

The Danish logarithmic plots are also attached in the appendix (11.3) in full. In order to make the 17 time spans from Denmark more manageable and comparable a table of the slopes has been made (Table 2). A negative slope will result in a R_0 value below 1 and a positive slope will result in a R_0 value above 1.

Table 2 This figure is a summary of the Danish logarithmic plots made in 7.1.1. The slope is read of the trendline and the R_0 value is calculated by equation: $R_0 = \frac{slope+\gamma}{\gamma}$, γ is set to 1/10 (time in days an individual is in the I compartment in the SIR model). The trendlines have been used to calculate the R_0 value for each timespan and are added to the table in the outermost right column.

Figure	Time span	Slope	R_0
Figure 8 A	02.03.2020-19.03.2020	0.0866	1.866
Figure 8 B	20.03.2020-31.03.2020	0.0538	1.538
Figure 8 C	01.04.2020-28.04.2020	-0.0121	0.879
Figure 8 D	29.04.2020-21.06.2020	-0,0106	0.894
Figure 8 E	22.06.2020-10.07.2020	-0.0104	0.896
Figure 8 F	11.07.2020-21.07.2020	0.0133	1.133
Figure 8 G	22.07.2020-04.09.2020	0.0094	1.094
Figure 8 H	05.09.2020-02.10.2020	0.0095	1.095
Figure 8 I	03.10.2020-08.11.2020	0.0167	1.167
Figure 8 J	09.11.2020-18.11.2020	0.0106	1.106
Figure 8 K	19.11.2020-22.12.2020	0.018	1.18
Figure 8 L	23.12.2020-30.12.2020	0.0188	1.188
Figure 8 M	31.12.2020-07.01.2021	0.0182	1.182
Figure 8 N	08.01.2021-18.01.2021	-0.0259	0.741
Figure 8 O	19.01.2021-21.02.2021	-0.0073	0.927
Figure 8 P	22.02.2021-14.03.2021	-0.0015	0.985
Figure 8 Q	15.03.2021-28.03.2021	0.0009	1.009

The trendslines can be used to calculate the difference in R_0 values to describe the effect of a given restriction or opening initiatives used by the Danish government. The first figure (Figure 8 A) shows a rapid growth for the first time span of the COVID-19 pandemic in Denmark with a R_0 value of 1.866 (Figure 8 A). The next time span shows a decrease of R_0 to 1.538 with the onset of a 1,000 people gathering ban from the Danish government (Figure 8 B). The gathering ban of 1,000 people was changed to a national lockdown on the 18th of March, this decreased the R_0 value to 0.879 (Figure 8 C). Almost a month later the Danish government introduced part one of a reopening program. This reopening slightly increased the R_0 to 0.894 (Figure 8 D). Part two of the reopening program shows a minimal increase of R_0 to 0.896 (Figure 8 E). The Danish government opened the borders for travel on the 26th of June and the time span after shows an increase of R_0 to above one with 1.133 (Figure 8

F). The time span after shows the effect of allowing 100 people to gather with a decrease of R_0 to 1.094 (Figure 8 G). The next span is shorter, and the Danish government introduced a requirement of wearing facemask in public transportation. In this time span a slight increased R0 can be observed with R0 for this time span being 1.095 (Figure 8 H). In the time span after the 100 people gathering limit is decreased to a 50 people gathering ban. Bars were allowed to open however they were required to close at 10 pm. In this time span an increase can be observed with a R_0 of 1.167 (Figure 8 I). A decrease in R_0 can be observed in the time span after with a R_0 of 1.106. In this time span the Danish government lowered the gathering ban from 50 to 10 people (Figure 8 J). This time span is also where the first confirmed incidence of the British B.1.1.7 mutation is observed in Denmark.

Closure of gyms and cinemas soon followed. This time span shows an increase of R_0 from 1.106 to 1.18 (Figure 8 K). Online teaching for 5th grade and above is introduced in the next time span with a small increase of R_0 to 1.188 (Figure 8 L). Malls, restaurants, and cafés close in the next time span which affects the R_0 with a slight decrease to 1.182 (Figure 8 M).

In the next time span the R_0 decreases to below 1 and in this time span the restriction of online school was changed to apply for all students. The R_0 is calculated to be 0.741 for this time span (Figure 8 N). In the next time span an even smaller gathering ban was introduced as it was lowered from 10 to 5. In this time span the R_0 increases to 0.927 (Figure 8 O). The next time span shows a R_0 value of 0.985 with the 0-4th graders back in physical school (Figure 8 P). The last time span used in the data is the reopening of small stores and other initiatives that increased the R_0 to 1.009 (Figure 8 Q).

7.1.2. Swedish logarithmic plots and R_0 values

The Swedish data of COVID-19 cases is starting from week 9 of 2020 to week 12 of 2021 have been split into 7 different time spans. The time spans show the general trend after an introduction of restrictions set into effect by the Swedish government that were likely to have an effect on the spread of COVID-19. A negative slope will result in a R_0 value below 1 and a positive slope will result in a R_0 value above 1.

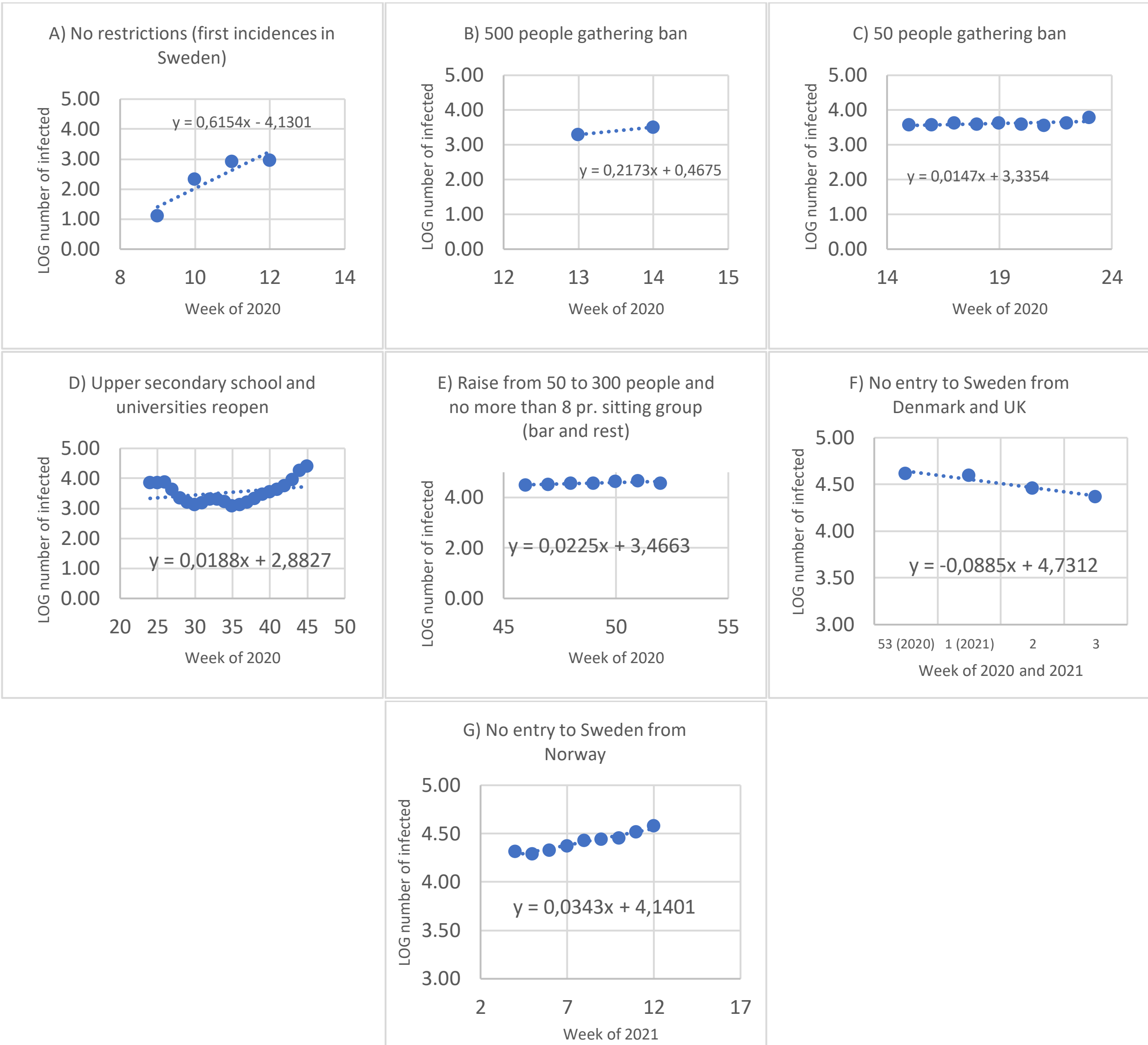


Figure 9 The logarithmic plot is created with the Swedish data from the Swedish Folkhälsomyndigheten from different time intervals. The X-axis represents the date of observed infections, and the Y-axis represents log values of observed infected individuals. The logarithmic values from the observed data set are plotted from each day. A trend line was added to determine the slope from the time interval between restrictions to obtain as accurate a value as possible. The slope of the trend line is used to calculate R_0. This has been done for each time span following a new restriction being put into effect.

The Swedish logarithmic plots are also attached in appendix 11.4 in full size. In order to make the 7 time spans from Sweden more manageable and comparable a table of the slopes has been made (Table 3). A negative slope will result in a R_0 value below 1 and a positive slope will result in a R_0 value above 1.

Table 3 This table shows a summary of the Swedish log plots made in 7.1.2. The slope is read of the trendline and the R_0 value is calculated by equation: $R_0 = \frac{slope+\gamma}{\gamma}$, γ is set to 1/10 (time in days an individual is in the I compartment in the SIR model). The trendlines have been used to calculate the R_0 value for each timespan and are added to the table in the outermost right column

Figure	Time span	Slope	R_0
Figure 9 A	Week 9-12 of 2020	0.6154	7.154
Figure 9 B	Week 13-14 of 2020	0.2173	3.173
Figure 9 C	Week 15-23 of 2020	0.0147	1.147
Figure 9 D	Week 24-45 of 2020	0.0188	1.188
Figure 9 E	Week 46-52 of 2020	0.0225	1.225
Figure 9 F	Week 53 of 2020 – Week 3 of 2021	-0.0885	0.115
Figure 9 G	Week 4-12 of 2021	0.0343	1.343

All plots except the plot from week 24 to week 45 (Figure 9 D) fit to a straight line. This line represents either exponential growth or decay. The difference in the calculated R_0 values is used to describe the effect of a certain government initiative. The first time span shows that the pandemic is growing at a rapid rate before any initiatives were taken, with an R_0 value at 7.154 over the first time span (Figure 9 A). This value is higher than the estimated value due to uncertainties in the data. Even though the value is high it still shows a decrease in R_0 when compared to the next time span. The R_0 for the next time span is also inflated compared to the 1.7 R_0 value [49]. The R_0 values seem more reliable and stable, the further into the pandemic they have been estimated. A decrease in R_0 is still seen after upper secondary school and universities has reopened. While an increase is seen in the next time span where the gathering ban is raised from 50 to 500 in the first week. The following week the gathering ban changed to eight people gathered at bars and restaurants pr. seating. Next time span (Figure 9 E) shows a further increase in R_0 from 1.188 to 1.225. The time span for week 53 of 2020 to week 3 of 2021 showed a decrease in R_0. This decrease in the R_0 value which is 0.115 will make it hard for COVID-19 to spread, therefore the low R_0 value might be caused by uncertainties in the data. The last time span (Figure 9 G) shows a large increase in R_0 to 1.343. In this time span the B.1.1.7 mutation of SARS-CoV-2 was introduced in Sweden [52].

7.2. Outputs from the SIR model

7.2.1. Danish outputs from the SIR model

The SIR model made in Python is modelled from the R_0 values calculated from the slope of the logarithmic plots from the Danish data (Figure 8 A-Q). The initial infected were estimated to match a realistic R_0 value for an uncontrolled COVID-19 pandemic. The number of infected reflects the number of infected between each change in restrictions.

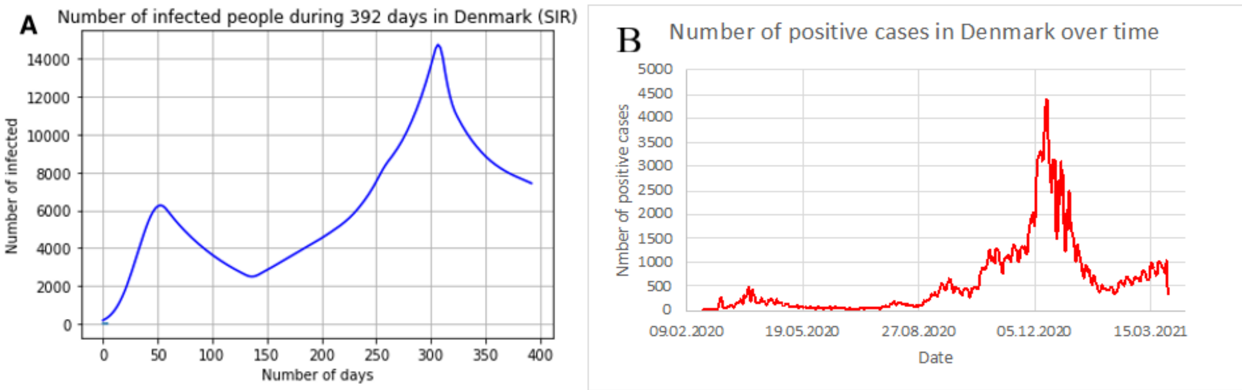


Figure 10 A The figure describes the number of infected for each time span in the Danish population according to the SIR model modelled in Python from data from SSI between the 2nd of March 2020 and the 28th of March 2021. The X-axis represents the number of days past since the first infected was diagnosed with COVID-19 in Denmark. The Y-axis represents the number of infected individuals at a certain point in time. Figure 8 B shows the number of positive cases in Denmark from the 2nd of March 2020 until the 28th of March 2021. The X-axis represents the dates, and the Y-axis represents the number of positive cases.

The graph of infected in the SIR model (Figure 10 A) matches the trends in the observed data (Figure 10 B). An increase in the number of infected can be observed prior to the first lockdown. The following months there is a decrease in infections before the second wave hits causing a rise in infected until the second lockdown is deployed (Figure 10 A-B). In the output of infected in the SIR model it is clear to see the two first waves of the pandemic. The same two waves can be seen in the observed data of infected Danes. The SIR plot sums all the infected from one time span, and therefore shows peaks with more infected than in the observed plot.

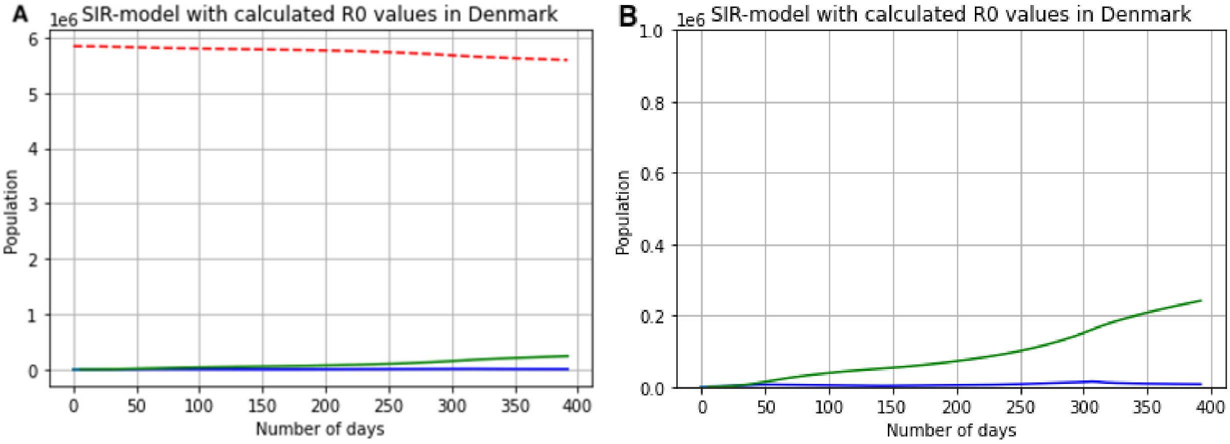


Figure 11 The figure describes the number of currently susceptible, infected, and recovered in the Danish population according to the SIR model, modelled in Python from data from SSI. The X-axis represents the number of days since the 24th of February 2020. The Y-axis represents the Danish population in millions. The dotted red line is the number of susceptible individuals in the Danish population. The green line is the recovered individuals, and the blue line is the currently infected individuals.

The dotted red line representing the susceptible part of the population will decreases depending on the amount of people infected and recovered. The amount of infected influence the rate of which individuals are moved from susceptible to recovered with more infected increasing the rate.

At approximately day 220-350 an increase in infected can be observed. The increase in infected, increase the rate of which susceptible individuals in the population moves to the recovered/dead stage. After day ~350 the number of infected individuals decrease, and the rate of which individuals move from susceptible to recovered/dead is decreased. The R_0 changes depending on the time span which explains the curved look of the graph. These values are the output from the SIR model with Danish data in Python. The output can be seen (11.5).

7.2.2. Swedish output from the SIR model

The SIR model made in Python is modelled from the R_0 values calculated from the slope of the logarithmic plots from the Swedish data (Figure 9 A-G).

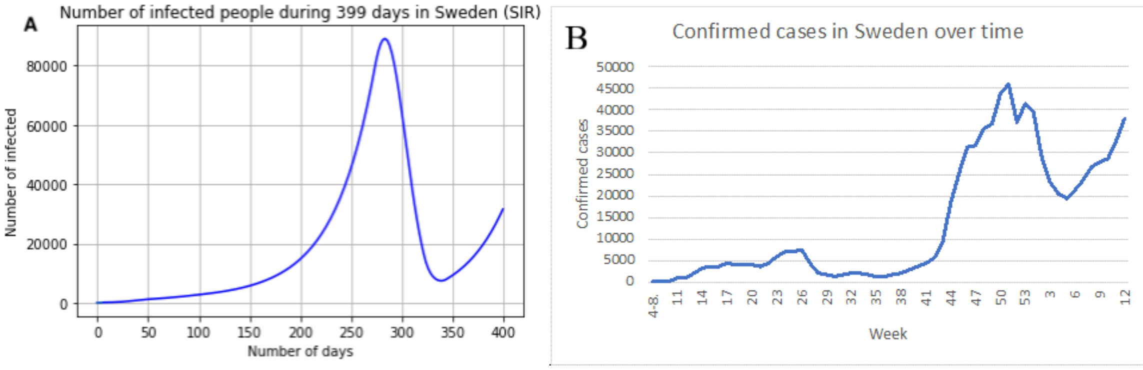


Figure 12 The figure describes the number of infected between time span in the Swedish population according to the SIR model modelled in Python from data from Folkhälsomyndigheten between the 24th of February 2020 and the 28th of March 2021. The X-axis represents the number of days past since the first infected was diagnosed with COVID-19 in Sweden. The Y-axis represents the number of infected individuals at a certain point in time.

The curve shows almost exponential growth from the initial day of collecting data to day ~275. The number of infected peaks at day ~275 before decreasing. The data follows the same trends as the observed data though the first wave is not visible on the SIR model. It seems like a single wave of COVID-19 and not two distinct waves. In the output of infected in the SIR model it is clear to see the last two waves of the pandemic. The same large peek can be seen in the observed data of infected Swedes. The SIR plot adds all the infected from one time span, and therefore shows peaks with more infected than in the observed plot.

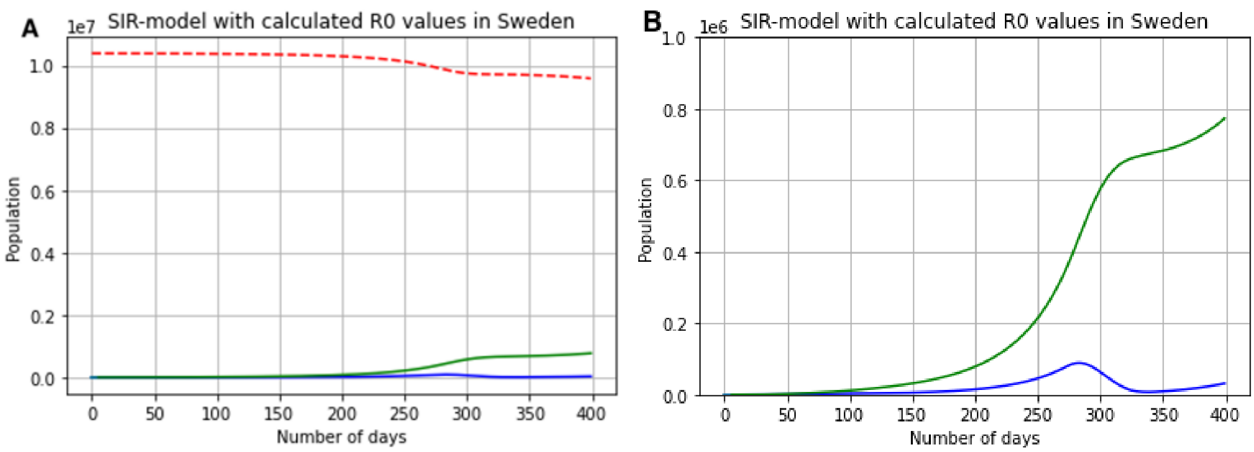


Figure 13 The figure describes the number of currently susceptible, infected, and recovered in the Swedish population according to the SIR model, modelled in Python from data from Folkhälsomyndigheten. The X-axis represents the number of days since February

24th 2020. The Y-axis represents the Swedish population in tens of millions. The dotted red line is the number of susceptible individuals in the Swedish population, the green line is the recovered individuals, and the blue line is the currently infected individuals.

The dotted red line representing the susceptible part of the population will decreases depending on the amount of people infected and recovered. The amount of infected influence the rate of which individuals are moved from susceptible to recovered with more infected increasing the rate.

At approximately day 200-280 an increase in infected can be observed. The increase in infected, increases the rate of which susceptible individuals in the population moves to the recovered/dead stage. After day ~280 the number of infected individuals decrease, and the rate of which individuals move from susceptible to recovered/dead is decreased. The R_0 changes depending on the time span which explains the curved look of the graph. These values are the output from the SIR model with Swedish data in Python. The output can be seen (11.6).

7.3. Comparison of R_0 values to incidence plots

Incidence numbers are a quick way to compare and analyze the impact of a given restriction have had on the further spread of COVID-19. Incidence numbers are relatively quick to make and when adding introduction date of restrictions, it visualizes the effect in a manageable way. An overall comparison of the Danish and Swedish incidence number will show how the spread on a national scale differ from each other.

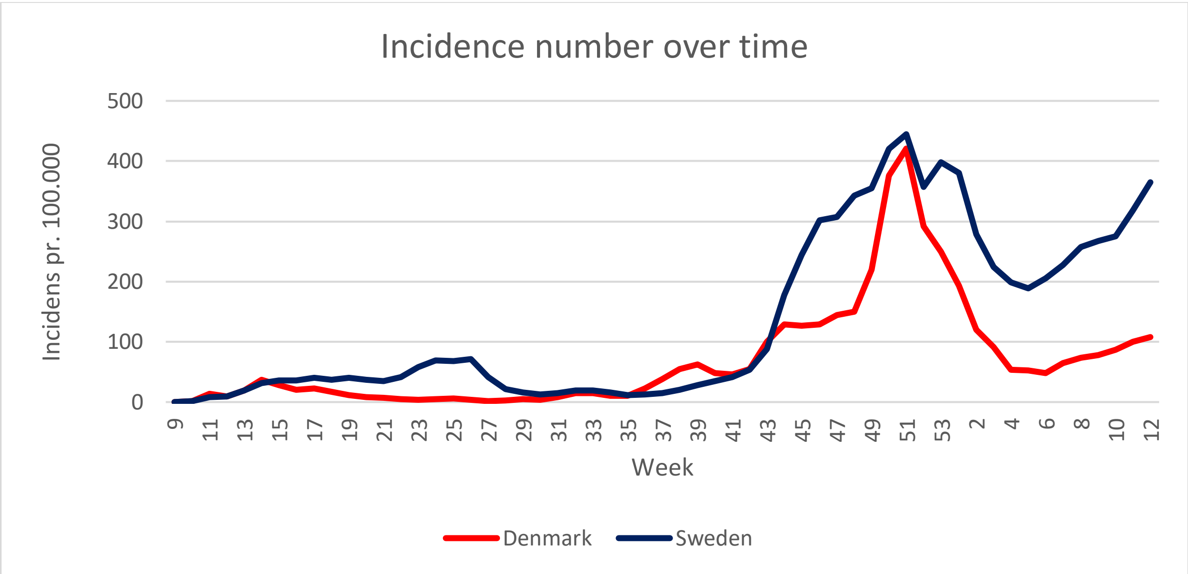


Figure 14 This figure shows a X-Y plot of incidence number pr. 100,000 citizen of newly infected individuals from week 9 of 2020 and week 12 of 2021. Numbers are calculated by taking weekly newly tested positive divided by the total number of inhabitants in the country times 100,000. This is done to make a more comparable graph when comparing the numbers from Sweden and Denmark. Note that the inhabitants already tested positive still count in the total population.

When comparing the Danish and Swedish incidence number from week 9 of 2020 to week 12 of 2021 the Danish incidence number is higher from week 9 to 14 of 2020 with a peak at week 14 reaching 37 pr. 100,000. In week 15 Sweden's incidence number stabilizes at 36-41 pr. 100,000 until week 22, where the Danish incidence number decreases in the weeks 20-31 to between 2 and 8 pr. 100,000. In weeks 24-26 Sweden's incidence number increases to between 68 pr. 100,000 and 71 pr. 100,000. Shortly after in week 28 Sweden's incidence number decreases to 11-21 pr. 100,000 staying low until week 38. The Danish incidence remains below 16 pr. 100,000 through weeks 19 and 35 before increasing continuously from week 35 till week 51. Then peaking in week 51, at the highest incidence number Denmark has experienced under the pandemic, at 421 pr. 100,000. The Swedish incidence number increases in a similar trend to the Danish. Increasing from 20 pr. 100,000 in week 38 with an almost exponential growth until week 51 where Sweden reaches its highest incidence number during the pandemic peaking at 444 pr. 100,000. Shortly after this the Swedish incidence number decreases steadily to 199 pr. 100,000 over the time span from week 52 of 2020 to week 4 of 2021. Following the peak, the Danish incidence numbers decreases from 421 pr. 100,000 in week 51 to 54 of 2020 in week 4 of 2021. In week 6 of 2021 and six weeks onwards both the Danish and Swedish incidence number experience an increase. The Danish incidence number increased from 48 pr. 100,000 to 107 pr. 100,000 and the Swedish from 204 pr. 100,000 to 365 pr. 100,000. Data collection is halted in week 12, though an increase in incidence number is a tendency seen in both the Danish and Swedish data.

7.3.1. Lockdowns effect on R_0

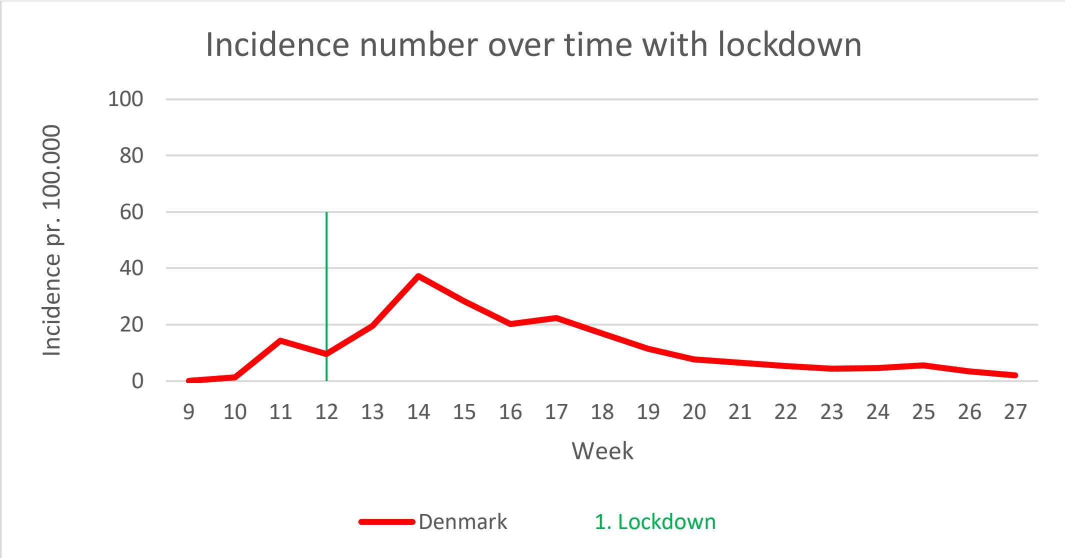


Figure 15 The figure show X-Y plot of incidence number pr. 100,000 citizen of newly infected individuals from week 9-27 of 2020. Numbers are calculated by taking weekly newly tested positive divided by the total number of inhabitants in Denmark.

In week 11 of 2020 all schools in Denmark closed, and in week 12 everything closed except essential shops and limited social gatherings to a maximum of 10 people were introduced. The trend of increasing incidence number continues for the expected two-week time span until week 12-14 where it peaks in week 14 with an incidence number of 37 pr. 100,000. The calculated R_0 value from the time span before the restrictions were set into effect was 1.86 representing an uncontrolled outbreak. After the first lockdown was initiated the R_0 value decreased to 1.53 which still represents a growing pandemic (Figure 8A-B).

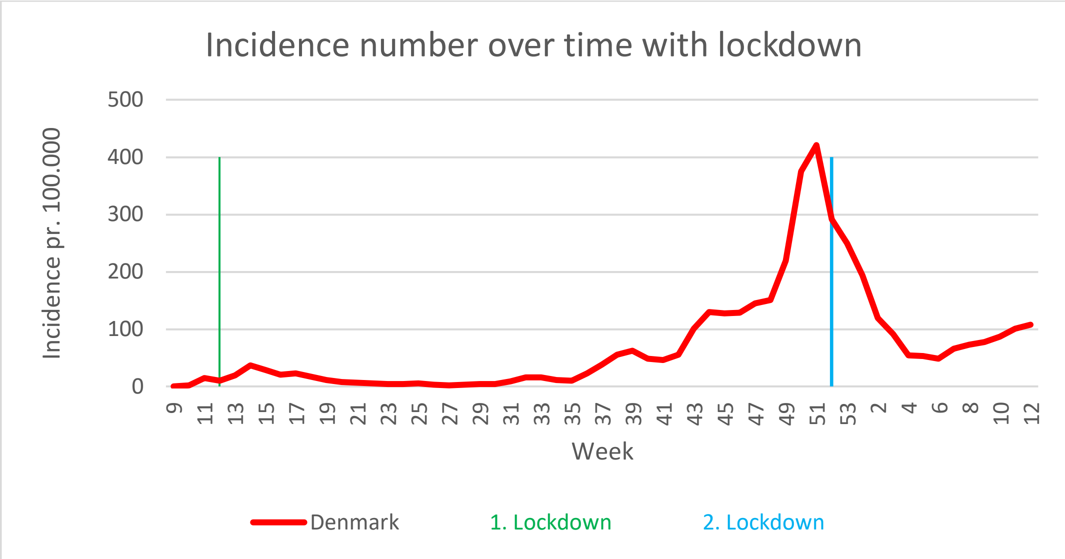


Figure 16 The figure shows X-Y plot of incidence number pr. 100,000 citizen of newly infected individuals from the weeks 9-53 of 2020 and week 1-12 of 2021. Numbers are calculated by taking weekly newly tested positive divided by the total number of inhabitants in Denmark times 100,000. Furthermore, first and second lockdown have been added with a green and blue line. Note that the inhabitants already tested positive still count in the total inhabitants.

The second lockdown, in week 52 of 2020, had a peak in incidence number a week prior to when the lockdown was set into effect, here the incidence number reached 421 pr. 100,000. Two weeks later in week 1 of 2021 the incidence number dropped to 193 pr. 100,000 which showed a decrease in newly infected individuals. The calculated R_0 value for the time span prior to the second lockdown was 1.188 representing a growing pandemic. In the time span after the second lockdown was put into effect the calculated R_0 value was 1.182. Although the time span (Figure 8 N) which starts 18 days after the lockdown was introduced the R_0 was 0.74, representing a decrease in infected (Figure 8K-N).

7.3.2. Closed borders effect on R_0

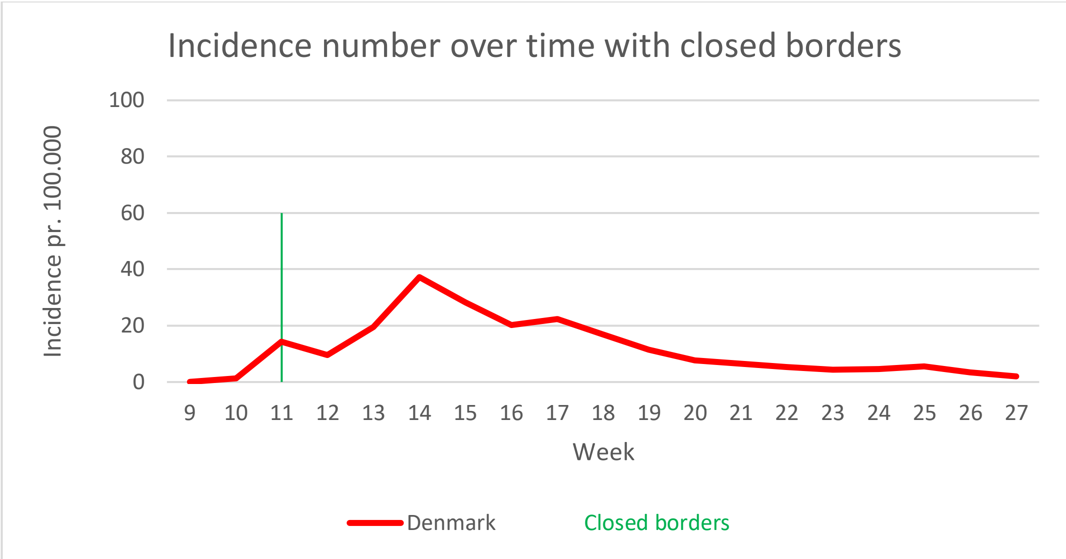


Figure 17 The figure show X-Y plot of incidence number pr. 100,000 citizen of newly infected individuals from the weeks 9-27 2020. Numbers are calculated by taking weekly newly tested positive divided by the total number of inhabitants in Denmark times 100,000. Furthermore, the restriction border closure has been added indicated by a green line. Note that the inhabitants already tested positive still count in the total inhabitants.

During week 11 of 2020 Denmark closed all borders for non-export/import travel. When introduced in week 11 the incidence was 14 pr. 100,000 and had a small drop the following week with an incidence at 9 pr. 100,000. The incidence number increased the following week with 19 pr. 100,000 in week 13 and peaked with 37 pr. 100,000 in week 14. The following weeks the incidence decreased steadily and in week 27 the incidence was 2 pr 100,000. The calculated R_0 value from the time span before the restrictions were set into effect was 1.86 representing the uncontrolled outbreak. After the first lockdown was initiated the R_0 value decreased to 1.53 which still represents a growing pandemic (Figure 8A-B).

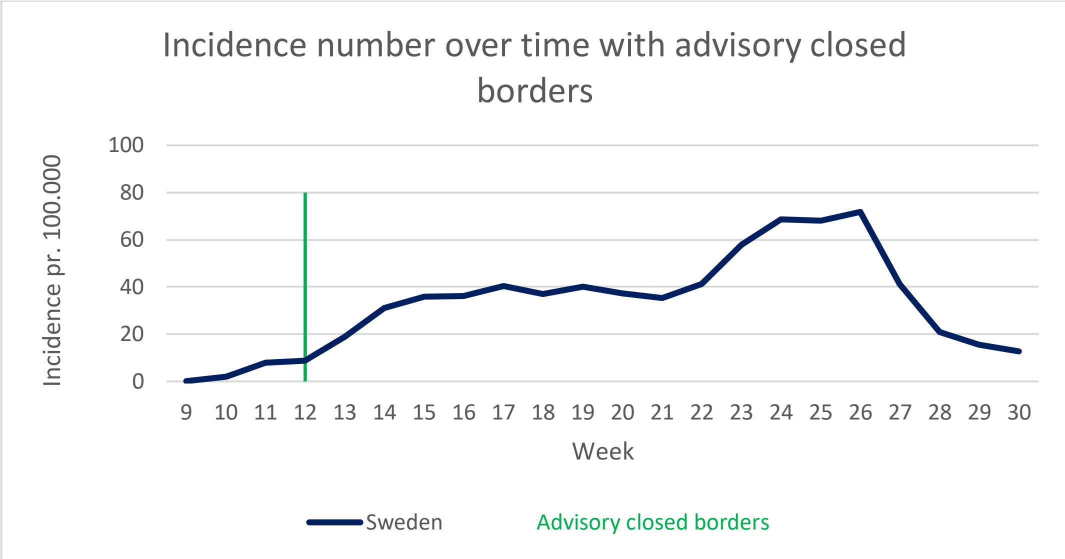


Figure 18 The figure shows a X-Y plot of incidence number pr. 100,000 citizen of newly infected individuals from the weeks 9-30 of 2020 Numbers are calculated by taking weekly newly tested positive divided by the total number of inhabitants in Sweden times 100,000. Furthermore, the restriction of advisory closed border has been added indicated by the green line. Note that the inhabitants already tested positive still count in the total inhabitants.

Sweden advised against domestic travel in week 12 of 2020. In this week the incidence number was 9 pr. 100,000. The following weeks the incidence increased to around 36 pr. 100,000 in week 15. From week 15 and the following 6 weeks (15-21) the incidence stayed around 37 pr. 100,000 with its lowest in week 21 where the incidence was 35 pr. 100,000 and its highest in week 17 where the incidence was 40 pr. 100,000. The calculated R_0 value prior to the ban of more than 50 people gatherings was 7.15. The following time span the R_0 value decreased to 3.14 (Figure 9A-B).

7.3.3. Decreased gatherings effect on R_0

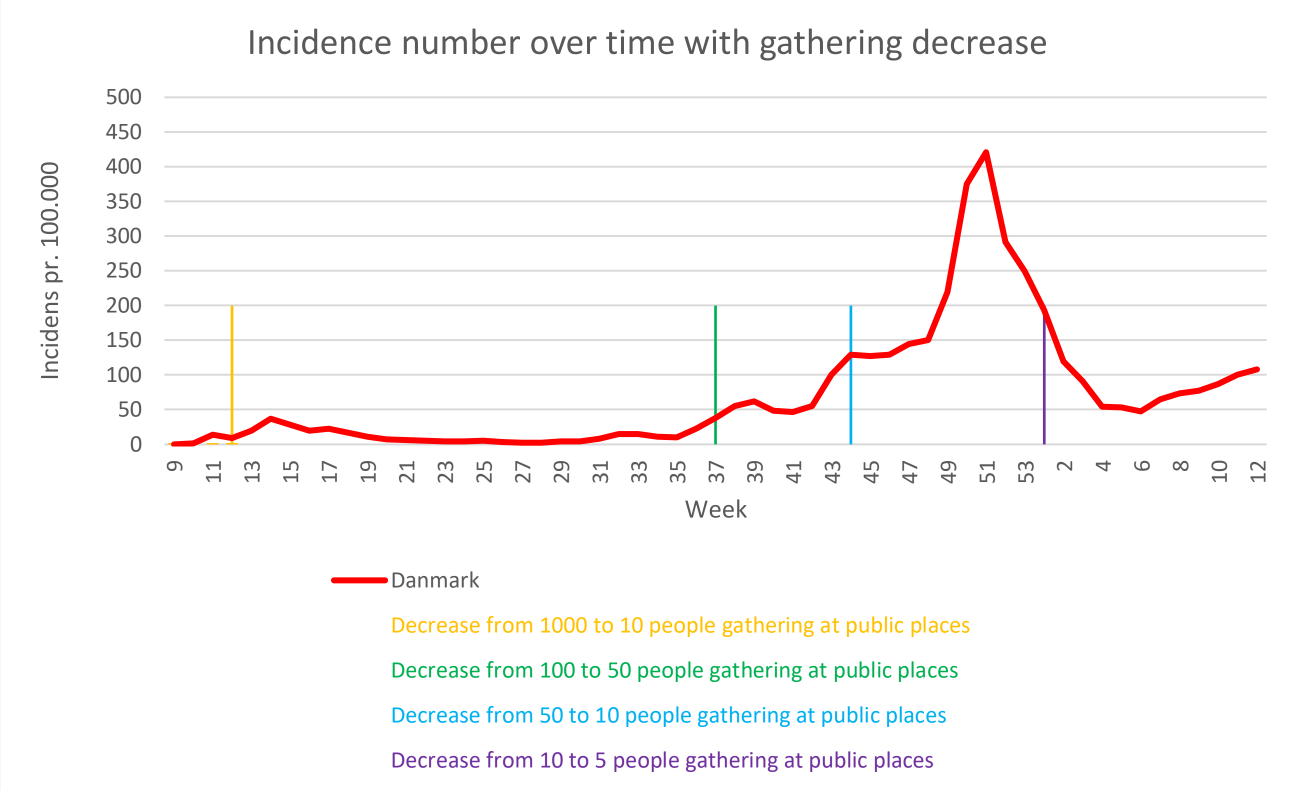


Figure 19 The figure shows an X-Y plot of incidence number pr. 100,000 citizen of newly infected individuals from the weeks 9-12 of 2020 and week 1-12 of 2021. Numbers are calculated by taking weekly newly tested positive divided by the total number of inhabitants in Denmark times 100,000. Furthermore, the different restrictions of gathering bans have been added indicated by a green, blue, yellow, and purple line. Note that the inhabitants already tested positive still count in the total inhabitants.

Denmark has had four major public gathering bans during 2020 and 2021. The first one in the beginning of the first lockdown, where gatherings of more than 10 people were prohibited. At this point the incidence rose from 9 pr. 100,000 in week 12 till 19 pr. 100,000 in week 13. A decrease is observed from week 14. The second prohibition being in week 37 with a decrease of 100 people allowed to gather in one place to 50 people. The third being a further decrease from 50 to 10 people gatherings in week 44 the same year. The weeks prior to week 37 shows a slight increase of incidence from 12 pr. 100,000 in week 35 and 13 pr. 100,000 in week 36. The weeks after, the first ban, showed a slight steady increase from 15 pr. 100,000 in week 37 to 28 pr. 100,000 in week 39. From week 38 throughout week 42 the incidence hovered around 50 pr. 100,000 with its lowest in week 41 with an incidence of 46 pr. 100,000 and the highest being week 39 with an incidence of 62 pr. 100,000. The third gathering ban was set into effect during week 44. During the prior two weeks an increase from 55 pr. 100,000 in week 42 to an incidence of 129 pr. 100,000 in week 44 can be observed. The following four weeks after the gathering ban showed almost the same incidence with a slight increase every week ending on an incidence at 150 pr. 100,000 in week 48. Around Christmas in the weeks

49-52 the incidence increases, peaking in week 51 with an incidence of 421 pr. 100,000. In week 1 of 2021 the ban was further decreased to 5 people. This was due to spread of the B.1.1.7. mutation of COVID-19. The incidence dropped from 193 pr. 100,000 to 119 pr. 100,000 in week 2 of 2021. The calculated R_0 value from the first gathering ban decreased from 1.866 before the ban till 1.538 after the ban. From the time span prior to the 100 to 50 maximum social gatherings was 1.094. The R_0 value remained the same in the following time span staying at 1.095. From a limitation of 50 to 10 people the R_0 was 1.167 in the time span where the restriction was implemented. In the following time span the R_0 value decreased to 1.106. After the last ban where 5 people were allowed at one gathering the R_0 value increased to 0.927.

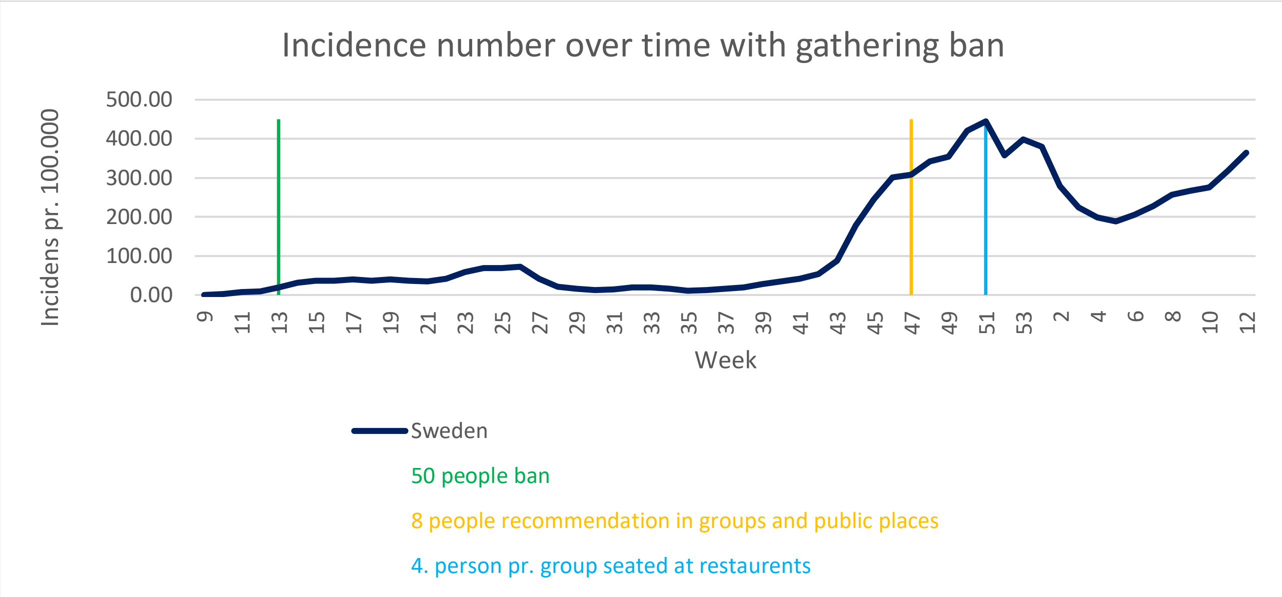


Figure 20 The figure shows a X-Y plot of incidence number pr. 100,000 citizen of newly infected individuals from weeks 9-53 of 2020 and 1-12 of 2021. Numbers are calculated by taking weekly newly tested positive divided by the total number of inhabitants in Sweden times 100,000. Furthermore, 50 people ban have been added indicated by the green line, an 8 people recommendation in groups indicated by a yellow line and a 4. Person pr. group seated at restaurants indicated by the blue line. Note that the inhabitants already tested positive still count in the total inhabitants.

Sweden introduced a ban on social gathering exceeding 50 people in week 13 of 2020. In week 13 Sweden's incidence number was 19 pr. 100,000 all though it increased the following 10 weeks after the restriction was put into effect. The second wave began in week 37 where Sweden had an increase in the incidence number and initiated a second restriction on social gatherings which reduced the amount of people at each restaurant and bar to eight people per seating. Sweden's gathering ban went from eight in week 47 and four 4 weeks later it decreased further to four people. In the weeks prior to the first ban in week 47 the gathering ban was set to 300 individuals. Looking at the first ban, the weeks prior has an increase from 245 pr. 100,000 in week 45 and further 302 pr. 100,000 in week 46.

In the week of the second gathering ban the incidence reached 308 pr. 100,000. The weeks following the gathering ban the incidence continues to rise. During the 4 weeks between the two bans the incidence increases steadily from 308 pr. 100,000 in week 47 to 445 pr. 100,000 in week 51. A slight decrease is observed directly after in week 52 with an incidence of 358 pr. 100,000. However, a general decrease from week 51 at incidence 445 pr. 100,000 to week 5 at incidence of 189 pr. 100,000 which is noticeable. The calculated R_0 value for the maximum of four people seated at bars and restaurant per group for the time span prior to the restriction was 1.188. The time span where the restriction was implemented had and R_0 value of 1.225 while the following time span had a R_0 value of 0.115.

7.3.4. Increased gatherings effect on *R0*

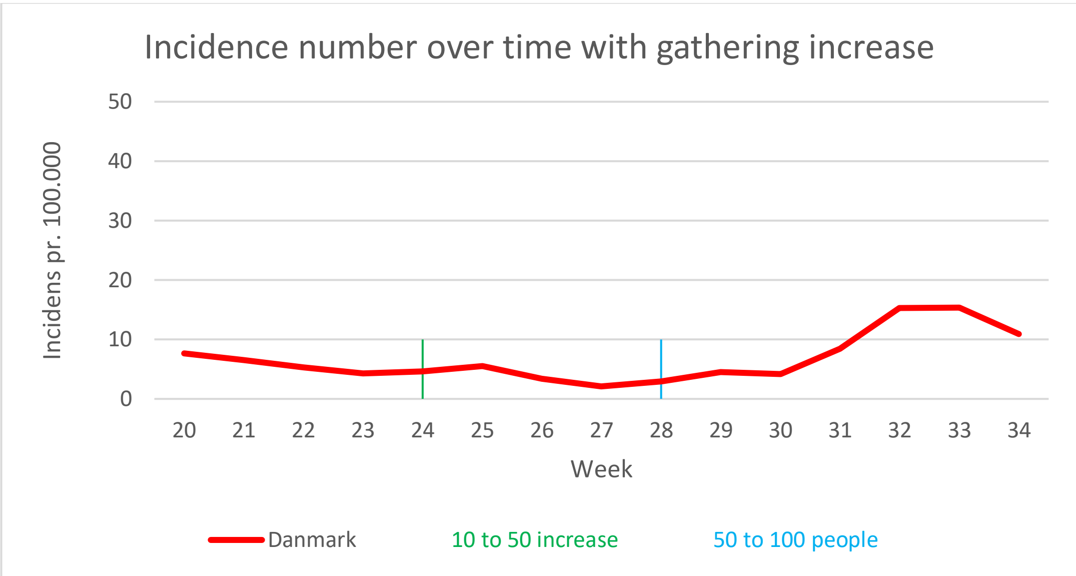


Figure 21 The figure shows an X-Y plot of incidence number pr. 100,000 citizen of newly infected individuals from weeks 20-34 of 2020. Numbers are calculated by taking weekly newly tested positive divided by the total number of inhabitants in Denmark times 100,000. Furthermore, the increase in social gatherings allowed from 10-50 people is indicated by the green line and 50-100 people indicated by the blue line have been added. Note that the inhabitants already tested positive still count in the total inhabitants.

Denmark increased the amount of people that were allowed to meet at a social public gathering in week 24 of 2020. Social public gatherings were increased from 10 to 50 people. Here the incidence was at 5 pr. 100,000. The following weeks the incidence decreased to 2 pr. 100,000 in week 27. The government decided to increase the number of people allowed to gather from 50 to 100 people in week 28. The following two weeks there were a slight increase in the incidence number with week 29 having an incidence at 5 pr. 100,000 and week 30 with an incidence at 4 pr. 100,000. From week 30 and onwards the incidence increased to around 15 pr. 100,000 in week 32 and 33. The calculated

R_0 value in the time span of the 10 to 50 maximum gathering size was 0.894. This is identical to the following time span where the calculated R_0 value was 0.896. When the maximum size for social gatherings was raised 50 to 100 individuals the time span saw an in increase in R_0 to 1.133 (Figure 8D-F).

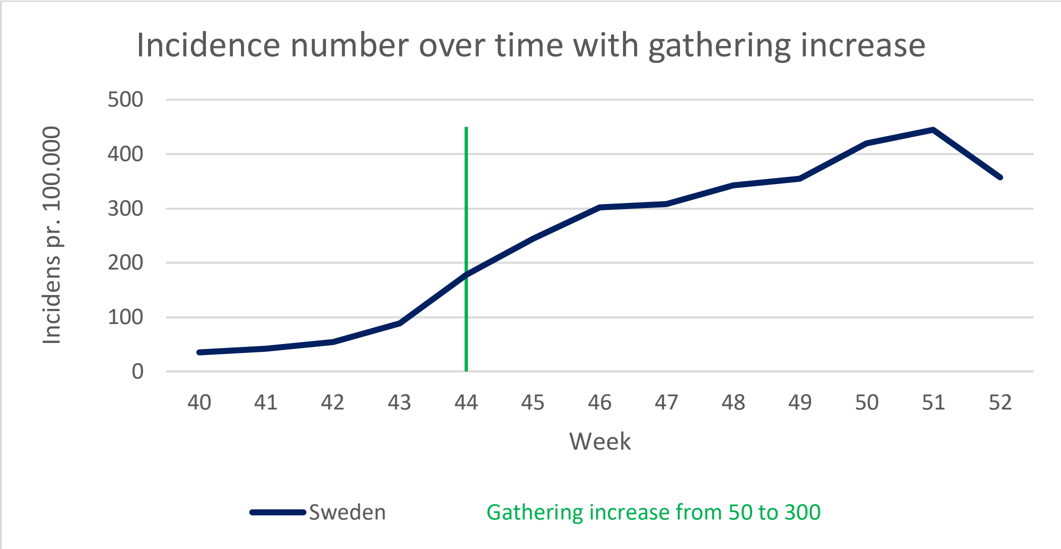


Figure 22 the figure shows an X-Y plot of incidence number pr. 100,000 citizen of newly infected individuals from the weeks 40-52 of 2020. Numbers are calculated by taking weekly newly tested positive divided by the total number of inhabitants in Sweden times 100,000. Furthermore, the increase of maximum size of social gathering from 50 – 300 has been added indicated by the green line. Note that the inhabitants already tested positive still count in the total inhabitants.

During week 44 of 2020 the Swedish government increased the maximum size of social gatherings from 50 to 300. The weeks prior to this the incidence numbers were increasing from 54 pr 100,000 during week 42 to 88 pr 100,000 during week 43. A gathering increase was introduced in week 44, during this week the incidence was 178 pr 100,000. The weeks after the loosening of restrictions shows an increase in the incidence with 245 pr 100,000 during week 45 and 302 pr 100,000 during week 46. During week 47 the incidence value starts to level off being only 6 pr. 100,000 higher than the previous week at 308 pr. 100,000. The incidence starts to increase in week 48 with 342 pr. 100,000 during this week. Note that during week 45 the Swedish government recommended the public to only be eight people seated at one gathering. The time span prior to the increase in maximum people allowed at social gatherings from 50 to 300 had a calculated R_0 value of 1.188 while the following time span had an R_0 value increase to 1.225.

7.3.5. The effect of face masks effect on R_0

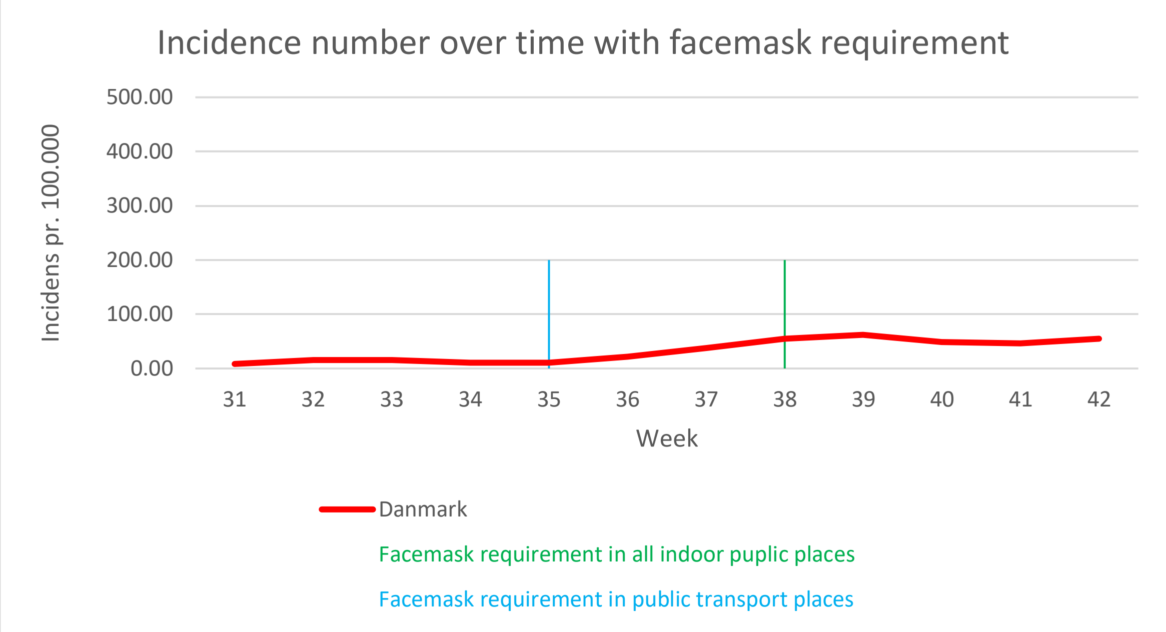


Figure 23 This figure shows an X-Y plot of incidence number pr. 100,000 citizen of newly infected individuals from the weeks 31-42 of 2020. Numbers are calculated by taking weekly newly tested positive divided by the total number of inhabitants in Denmark times 100,000. Furthermore, the different restriction of wearing face masks has been added indicated by a green and blue line. Note that the inhabitants already tested positive still count in the total inhabitants.

Denmark introduced a requirement for use of face masks in public transport in week 35. The weeks prior to this the incidence showed a decreasing trend when dropping from 15 pr. 100,000 in week 33 to 10 pr. 100,000 in week 34. In week 38 of 2020 Denmark tightened the restrictions by including all public indoor areas. In the weeks prior to the tightened restrictions the incidence showed an increasing incidence at 22 pr. 100,000 in week 36 and 38 pr. 100,000 in week 37. Week 38 showed an incidence number of 55 pr. 100,000 thus Denmark induced the facemask requirement at all indoor public places. The following week showed a slight increase in the incidence to 62 pr. 100,000. In week 40 the incidence lowered to 48 pr. 100,000 and stayed at this level the following weeks 41 and 42. In general from week 38 to 42 the incidence number oscillated around 55 pr. 100,000 with the highest in week 39 and the lowest in week 41 with an incidence of 62 pr. 100.000 and 46 pr. 100,000 respectively. The calculated R_0 value from the time span prior to face masks being required in indoor public areas was 1.094. In the time span it was implemented the R_0 value stayed at 1.095 and the time span following the requirement the R_0 value increased to 1.167 (Figure 8G-I).

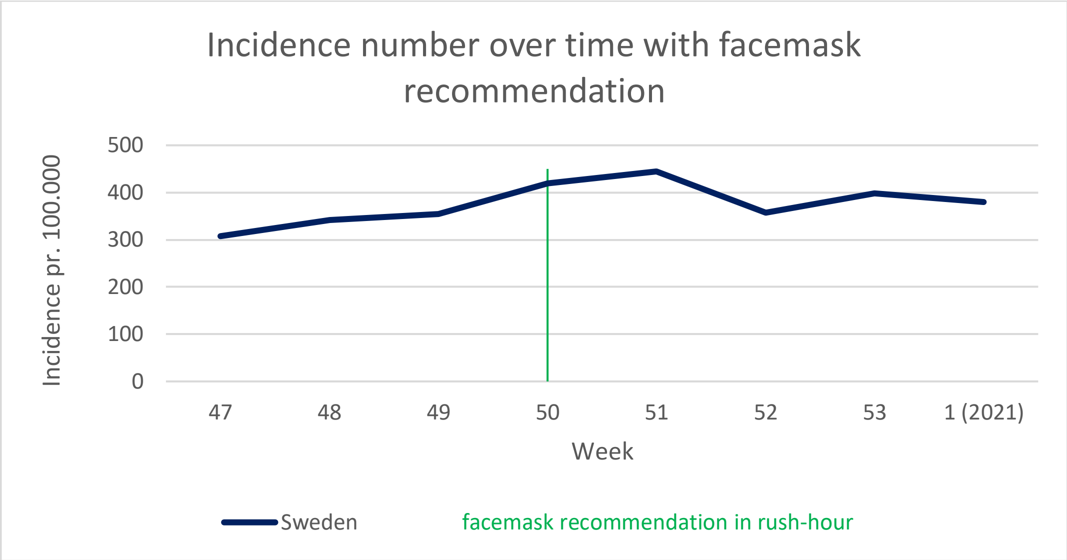


Figure 24 This figure shows an X-Y plot of incidence number pr. 100,000 citizen of newly infected individuals from the weeks 9-30 of 2020. Numbers are calculated by taking weekly newly tested positive divided by the total number of inhabitants in Sweden times 100,000. Gatherings of 50 people or more banned indicated by the green line. Note that the inhabitants already tested positive still count in the total inhabitants.

Sweden introduced the recommendation of wearing face masks in public transport later than Denmark. The use of face masks was recommended from week 50 of 2020. The incidence number the previous weeks were 342 pr. 100,000 in week 48 and had an increase to 355 pr. 100,000 in week 49. In week 50, during the week of the recommendation, the incidence reached 421 pr. 100.000. The following two weeks, the incidence increased to 445 pr. 100,000 in week 51 and decreased to 358 pr. 100,000 in week 52. A slight increase from week 52 to 53 is observed with an incidence of 398 pr. 100,000 in week 53 2020 and a small decrease in the first week of 2021 with an incidence of 380 pr. 100,000. In the time span where the recommendation of wearing face masks during rush hour the R_0 value has been calculated to 1.225, the following time span had a R_0 value of 0.115. (Figure 9E-F)

8. Discussion

This discussion covers the restrictions used by the Swedish and Danish governments and their effect on the reproduction number. Certain uncertainties with the data and the difference in collected data have been discussed as well as parameters that could play a role in the spread of COVID-19. Furthermore, the effect of new SARS-CoV-2 mutations on the infection rate have been discussed.

8.1. Uncertainties in methods and data

There are several parts of the results that did not correspond to the expected outcomes according to the literature. This can be due to multiple factors which this part of the discussion focuses on. The first part of this discussion focuses on the calculated R_0 values from the logarithmic plots and the second part focuses on the possible errors connected with the simple SIR model.

8.1.1. Uncertainties associated with R_0

The R_0 values in this thesis are based on observed data on new positive cases of COVID-19 in Denmark. Therefore, multiple factors can impact the R_0 values in the different time spans. An uncontrolled COVID-19 pandemic has an R_0 value at around 2.5 [51]. In Sweden these values are said to be 1.7 [49] The largest uncertainties in the calculated R_0

Table 3) are seen in Sweden. First and second calculated R_0 values are 7.153 and 3.173, which are large overestimates compared to the value of 1.7 of the uncontrolled pandemic in Sweden. Compared to the similar time span, the Danish R_0 values (Table 2) are calculated to be 1.866 and 1.538. Even though these values are a better fit for the uncontrolled pandemic R_0 values, these might still be skewed. The skewed values in the beginning of the pandemic can be caused by two factors: (I) The amount of people who were initially infected is unknown which impacts the perceived amount of susceptible people expected to be infected [53]. (II) Testing capacity was limited, which meant the only people getting tested were people emitted to hospitals. People who had non-acute symptoms were asked to self-isolate and were not tested [53]. These factors inflate the R_0 values causing it to be unreliable and being outliers compared to the rest of the data set. When looking further into the Swedish R_0 values it is observed that the calculated value of 0.115 in the end of the year 2020 and the beginning of 2021 seems to be lower than what would be expected. Around this time Sweden prohibited entrance to Sweden from Denmark and the United Kingdom, due to the spread of the more contagious B.1.1.7 strain (11.1). This ban might have had a positive effect regarding containment of the B.1.1.7 strain. In this time span Sweden also had less COVID-19 tests on a weekly basis compared to the week prior. A drop from around 270,000 weekly tests to 200,000 weekly tests can be observed. This might also have had an influence on the lowered R_0 value since less people are being detected.

Another factor that can influence the R_0 values when using this method of calculation is the number of datapoints in the time spans, e.g., weeks and days. More datapoints makes data more reliable especially when using the regression line for further analysis. In this case for the R_0 values of 7.153, 1.538 and 0.115 the time spans have been between 19 and 30 days. This leaves only 2-4 datapoint in the graphs compared to 22 in Sweden's largest time span. The short time spans (Figure 9 A+F)(Figure 8B), can be significantly impacted by a few changes in R_0 especially the Swedish data since it is reported weekly. (Figure 9 A+F) only span over four data points, because of this, a single data point will have a large impact on the R_0 of the entire time span. The Danish data has the advantage of being reported daily, thus not as exposed to influence from a single data point even if the time span only spans 11 days. These short time spans with few data point can possibly also influence the calculated R_0 values since the slope of the regression line is used to calculate R_0. When comparing this to Denmark, all the time spans have more datapoints since data is being gathered daily, not weekly. This makes a time span in Denmark of 21 days more reliable since there are 21 data point and not three as in the Swedish data. Based on this the Danish R_0 values should be more reliable.

8.1.2. Errors and omissions in SIR model

In the SIR model the two parameters β and γ must be defined with a value. In this thesis β is dependent on R_0. As described and discussed earlier R_0 is based on observed data from Denmark and Sweden, and with observed data comes uncertainties. These uncertainties translate into the SIR model, because the R_0 values are used to define the values of β. This makes the uncertainties in the SIR model larger, since some uncertainties are already associated with the model.

The SIR model makes assumptions which can never be replicated in reality. The SIR model assumes everyone has a chance to meet everyone allowing the infections to occur more randomly throughout a population. This makes it impossible for the SIR model to take local lockdowns into account if only a small portion of the population is infected. People are typically infected by people they interact with daily, either close friends/family or co-workers, or in large crowds where people move in close proximity (concerts or bars) [10].

Previously in data processing other methods were used to predict and process the outcome of the SIR model and R_0. The R_0 values were inflated when trying to model the pandemic from the beginning, though this might have been due to uncertainties surrounding unknown cases and change in testing strategies later deployed. When attempting to hand-fit the R_0 in Python, trying to replicate the observed data of the infected, another problem occurred. The number of recovered increased beyond the total infected, becoming increasingly apparent after fitting the first few time spans. While Sweden had ~800,000 total infected the model had ~3,900,000 recovered, far exceeding the total amount of infected individuals.

It was also attempted to create a trendline across the data for each time span. The trendline could not properly describe the time span because the data in specific time span was not consistent especially regarding longer time spans (longest time span is 161 days for Sweden) which might create uncertainties.

The data has been split into multiple sample sizes attempting to reach the observed results. The splits have been made into following sizes without reaching the desired results, day by day, week by week and time span between restrictions.

The SIR-model used in this thesis does not account for asymptomatic infected individuals in the population, creating a blind spot for the model's output. A solution for this uncertainty in the outcome could be the addition of a new compartment. The compartment would be for asymptomatic (*A*) individuals creating the SAIR model. When creating the SAIR model new parameters must be defined. The SAIR model will now include a new path for the asymptomatic, thus creating a movement of asymptomatic individuals from *S* to *A* and then directly to *R*.

Asymptomatic individuals in the population can lead to a prolonged pandemic in countries that does not offer testing for everyone, but only offers tests to symptomatic individuals. A solution for this issue could be to offer mass-testing, thus minimizing the risk of infectious asymptomatic people infecting the susceptible part of the population.

8.2. Restrictions, mutations, and other factors that play a role on the spread of COVID-19.

The implementation of different restrictions and modifying them to the current spread of SARS-CoV-2 might play an important role in reducing the spread. The first part of this discussion focuses on the individual restriction and the effect of these shown in the data. The second part concentrates on the arrival of the B.1.1.7 strain in the two countries. The last part focuses om some of the factors that the Danish and Swedish government did differently like mass-testing and difference in public gatherings.

8.2.1. Restrictions and their effect on the spread of COVID-19

The Danish and Swedish government used a variety of different restrictions to try and limit the spread of COVID-19. The different restrictions have had different impacts on the pandemic, with certain initiatives having a greater effect and being more efficient at reducing the spread of COVID-19. By looking at the increases and decreases in R_0 values both when the restriction is implemented and when it is removed it should be possible to find the most efficient restriction. The Danish restriction time span (Figure 8 B) has a R_0 value of 1.53 while (Figure 8 C) has 0.87. Time span (Figure 8 B) starts when the first restriction was put into effect prohibiting gatherings exceeding 1,000 people. The Time span (Figure 8 C) started when the first lockdown was initiated limiting gatherings to a maximum of 10 and closing malls, bars, restaurants, gyms, etc. (Figure 8B-C). The reduction in social interactions reduced the spread of COVID-19 which reduced the infections caused by super spreaders [10]. During the second lockdown, similar restrictions were introduced with schools, malls, gyms, bars and restaurants closing as well as banning social gatherings exceeding 5 people (Figure 8 M-O). Between (Figure 8 M-N) the R_0 decreased from 1.18 to 0.78 which was the biggest drop in the time span. The drop was likely caused by the fact that multiple restrictions were put into effect in close proximity. It is suspected that the reason Denmark could not maintain the low R_0 value which increased in the following times spans, was because of the B.1.1.7 mutation becoming more prevalent.

The implementation of face masks did not have a negating effect on the calculated R_0 value or the incidence number pr. 100,000 in Denmark (Figure 7H-I)(Figure 23). In Sweden face masks were only required during rush hour in public transport which might not have had the same impact as being required to wear facemask during all indoor activities in public settings. This was unexpected to occur with the effect of face masks on viral spread [26]. This could be caused due to a variety of factors. (I)

Seasonal changes impact COVID-19 spread, the requirement for face masks were set into effect in the early fall, a time where people mostly stay indoors. This would cause an expected increase in infected individuals unless being negated due to restrictions. (II) The requirement of wearing face masks was implemented shortly after two restrictions had been lifted (gatherings of 100 people now allowed and travel to European countries except Sweden and Portugal). This would cause an increase in physical social interactions which would negate the decrease in spread otherwise caused by the facemask requirement.

The Swedish government prohibited entry from the United Kingdom and Denmark just before Christmas (the 21st of December 2020). This has possibly slowed the influx of the B.1.1.7 mutation from these countries. Even though the first case was detected the 26th of December 2020 it is possible that effective contact tracing and isolation delayed the spread of the first wave of B.1.1.7 mutation in Sweden. With that said, it is unlikely that the travel ban between countries would have lowered the R_0 with 1.11 in a 4-week time span suggesting that the infection rate would move towards 0. However, the Danish government closed the borders as part of the first lockdown which effectively lowered the R_0 from 1.538 to 0.879. This seems efficient however closed borders was introduced amongst other restrictions such as closed restaurants and bars. Thus, no clear indication can be observed about if it is specifically the closing of the borders or if it is the combination of the restrictions introduced. One way of getting closer to which restriction is most efficient would be to look at the effect of the removal of a restriction. During the first reopening of Denmark the biggest change to the R_0 is seen when the citizens were allowed to travel again. This is seen in Figure 7 F which shows an increase of R_0 from 0.896 during part two of the first reopening to 1.133 when travel was allowed. This could suggest that the prohibition or limiting of travel between countries might play an important role in keeping the R_0 value of COVID-19 below 1.

8.2.2. B.1.1.7.

In week 46 the Danish health authorities announced the first case of the SARS-CoV-2 B.1.1.7 mutation in Denmark. Around this time the restrictions in Denmark changed to include a 10 people gathering ban, facemask in all indoor public places, homeschool for 5-8th graders in several municipalities as well as closed restaurants, gyms, and cinemas. In the previous time span the R_0 was calculated to 1.167 (Figure 8 I) and in the following time span there seems to be an increasing trend.

From the first case of B.1.1.7 mutation the R_0 increases from 1.106 to 1.18 later 1.188 and finally 1.82 (Figure 8 J-M). The trend of an increasing R_0 could be a result of the hydrophobic change mutation in B.1.1.7's spike protein and be a consequence of the increased affinity towards the ACE2 binding site that has increased the infectiousness. R_0 is affected by the mutation due to the change in affinity that changes the β parameter also used in the SIR model. The increased β increases the probability of moving from the S compartment into the I compartment thus increasing the total amount of infected. However, there might be another explanation. The increased spread happened during Christmas, an explanation for this surge in confirmed cases could be a result of increased domestic travel resulting in the increased risk of new COVID-19 clusters forming in new parts of the country. A lower social distance would result in higher probability of aerosol transmission also changing the β value. As a response to the increased transmission rate the Danish government lowered the gathering ban from 10 to 5. This seems to influence the R_0 in the time span ranging from the 8th of January 2021 to the 18th of January 2021 decreased to 0.741.

The first case of the B.1.1.7 strain in Sweden was recorded on the 26th of December 2020 (week 52). As discussed earlier a decrease in the R_0 value at this time seems unlikely (8.1.1). Even though the first case was confirmed in December the B.1.1.7 strain should not impact the R_0 this early. The Swedish health authority estimated the share of the B.1.1.7 strain to be between 0 and 27 percent the 23rd of February 2020 [54] thus an effect on R_0 from the B.1.1.7 in December is unlikely.

8.2.3. Factors not associated with restrictions that impacts R_0.

Two of the major factors not associated with restrictions that might impact the R_0 value, would be superspreading events and new COVID-19 mutations. While this thesis focuses on the B.1.1.7 variant of the virus, other mutations might play a role in the spread of COVID-19. The B.1.1.7 deletion mutation and nonsynonymous amino acid change mutation that made transmission between hosts more effective and gave the new strain a better fitness thus raising the infection rate. When reviewing the restrictions used by Sweden and Denmark it becomes clear that both countries had to introduce further restrictions when the B.1.1.7 strain became prevalent. While the national R_0 value was close to 1 for both Denmark and Sweden (Figure 8 J & Figure 9 E) the share of which strain was the most dominant changed. Though the novel SARS-CoV-2 is estimated to have a R_0 value of 2.5 under uncontrolled environments a shift in the dominant strain for the population could change β thus changing R_0 giving a larger amount of infected.

Another factor that plays a role on the R_0 value is testing capacity and the general policy on when a person can get tested. One example of the difference in initiatives is that Denmark started mass-testing while Sweden offered a test to everyone who had symptoms. By mass-testing a population it is possible to catch some of the infected that are asymptomatic before they cause a super spreading event. The lack of mass-testing in Sweden could result in more superspreading, thus increasing the probability of a higher dark number. This difference has an indirect effect on R_0 with a dark number increase skewing the data on the time axis for the Swedish data. The general policy on testing has changed and with the implementation of the antigen test and an expanded test capacity the Danish government had the opportunity to collect accurate data of how the COVID-19 B.1.1.7 strain is distributed throughout the population. Super spreader events can have an impact on the R_0 value due to the high amount of people that could get infected by a few persons. There are several studies proving that super spreaders contribute with a large quantity of the infected in countries such as South Korea, China, Jordan and USA [10], [22].

A natural factor that has a noticeable impact on the R_0 value are the seasons in both Denmark and Sweden, that impact the R_0 value making it naturally decrease in the warmer months and increase in the colder months [9]. This is caused by behavioral changes, with individuals spending more time indoors during the winter and less during the summer. During the summer people ventilate the indoor areas more often and outdoor activities are a more common occurrence. This effectively decreases the chance of aerosol transmission thus lowering the R_0 [55].

9. Conclusion

It is difficult to pinpoint the exact restriction with the largest impact in reducing spread of COVID-19. Closing malls, bars, restaurants, hairdressers etc. seems to reduce the R_0 value and incidence number by the largest margin. The restriction is often accompanied by border closures and/or a tightening of the maximum size of social gatherings. The B.1.1.7 mutation has had both an impact on the efficiency and type of restrictions implemented by the two governments during the pandemic.

In order to control the spread, it seems necessary to follow the spread closely by mass-testing in order to act quick on a sudden increase in the R_0. By closing borders and sequencing the positive tests it is possible to control the amount of mutations and prevent the spread of these. The data used in this thesis suggest that the use of facemask has less of an effect than social gathering bans, however it is not conclusive because the introduction to facemask was accompanied with introductions of reopening initiatives. Though some conclusions of which restriction is more efficient can be made, by the data presented in this thesis, it is difficult to pinpoint an exact one due to the introduction of multiple restrictions at the same time.

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11. Appendix

11.1. Appendix 1; Sweden event timeline

1. 31-01-2020 – First case confirmed.
2. 12-03-2020 – Arrangement with more than 500 people are banned.
3. 14-03-2020 – All non-essential traveling to other countries is advised against.
4. 17-03-2020 – Travel to countries non-EU countries is advised against. Furthermore, Universities and upper secondary schools are recommended using online teachings.
5. 27-03-2020 – Arrangements with more than 50 people are banned.
6. 29-05-2020 – Upper secondary schools and universities are opened again.
7. 04-06-2020 – All people with Covid-19 symptoms are offered a test no matter the severity of the symptoms. However not all regions offer this.
8. 13-06-2020 – All domestic travel is open but still under the requirement of social distancing.
9. 27-08-2020 – Public health authorities recommend that the assembly ban this raised to 500 individuals.
10. (20-29)-10-2020 – More regional recommendations are set into place. Among Skåne, Uppsala and Stockholm. Recommendations involve social distancing of 1,5 meters and to avoid restaurants, malls, and fitness centers. Some also recommends avoiding public transports.
11. 01-11-2020 – The government follows the public health authorities' recommendations and raise the gathering ban from 50 to 300 individuals at events where people can be seated with 1,5 meters between.
12. 03-11-2020 – Government bans more that 8 people in groups seated at restaurants and bars.
13. 16-11-2020 – Government recommends no more than 8 people in all public places. Also recommends people living in social bobbles (only see the same 7 people for the period)
14. 24-11-2020 – Recommendations made the (20-29)-10-2020 are now set in place in all regions.
15. 14-12-2020 – Recommendations are made into prohibition; 8 people in a group & 1,5 meters distance etc.
16. 18-12-2020 – Prohibition of 8 people at restaurants etc. Are lowered to 4 people. Face mask are now recommended in public transports between 07-09 am and 04-06 pm however not a requirement.
17. 21-12-2020 – Prohibition of entry from Denmark and United Kingdom.
18. 26-12-2020 – First case of B.1.1.7 confirmed.
19. 27-12-2020 – First vaccine administered.
20. 01-01-2021 – Entry from United Kingdom allowed with special permit.
21. 11-01-2021 – Prohibition in stores, swimming pools and fitness Centers. No more than one person per 10 square meters.
22. 24-01-2021 – Prohibition of entry from Norway due to B.1.1.7 cases.
23. 15-03-2021 – As of this date no change in the restrictions have been made.

The Swedish timeline is constructed based on information provided by official government websites [40] and [4].

11.2. Appendix 2; Danish event timeline

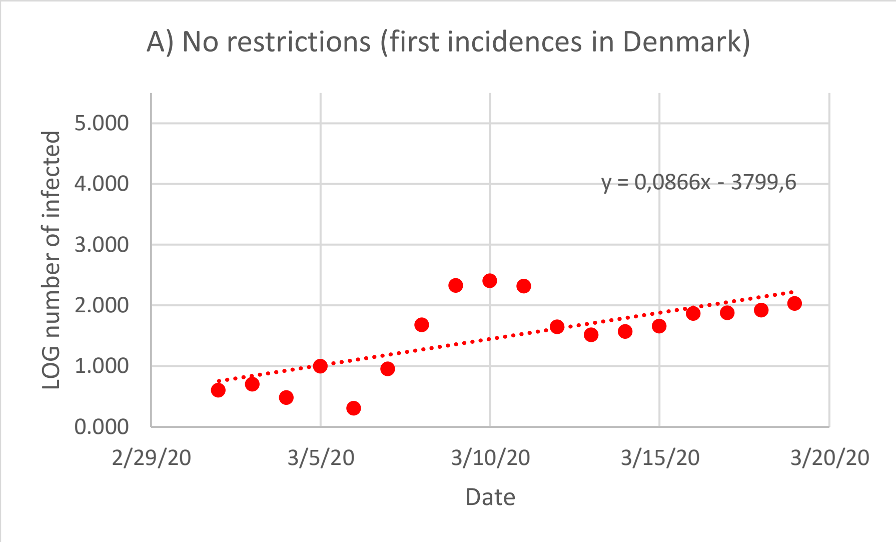
1. 27-02-2020 – first case confirmed.
2. 03-03-2020 – 10 people confirmed infected.
3. 04-03-2020 – 15 people confirmed infected.
4. 06-03-2020 – All events with more than 1000 people are banned, government recommends avoiding handshakes, hugs, and kisses.
5. 09-03-2020 – One high school closes due to a couple of confirmed cases.
6. 10-03-2020 – middle school class in quarantine. 156 positive cases, 770 people in quarantine. Keep distance in trains and busses.
7. 11-03-2020 – middle school closes where class is already in quarantine after two positive cases. 514 positive cases, 1231 in quarantine. Workplaces are closing for at least 14 days.
8. 13-03-2020 – you are allowed to be with friends. Travelling are being discouraged.
9. 14-03-2020 – Danish borders are being closed.
10. 15-03-2020 – all school are closed.
11. 18-03-2020 – gatherings of more than 10 people are prohibited, restaurants, malls, and hairdressers close. The Danish queen gives a speech to the country about the virus and its seriousness.
12. 15-04-2020 – 1 part of the reopening. 0-5 grade are going back to school. More people are going back to work.
13. 17-04-2020 – Hairdressers open.
14. 20-04-2020 – outdoor sports activities open again, but with no physical contact.
15. 11-05-2020 – malls are opening again.
16. 18-05-2020 – 6-10 grade are going back to school. Boarding schools are opening as well as cafés, restaurants, and pubs until midnight and only with seating people.
17. 08-06-2020 – second part of the reopening. Max of 50 people gathered. Fitness, swimming pool and Tivoli (amusement park) open. Opening of indoor sports activities with matched against other teams.
18. 15-06-2020 – boarders are being opened for Germany, Norway, and Iceland. Danes can as well travel to these countries.
19. 27-06-2020 – travel to all of Europe except Sweden and Portugal are being allowed.
20. 08-07-2020 – gatherings of max 100 people.
21. 31-07-2020 – recommendation of wearing face masks in public transport.
22. 06-09-2020 – many infected in Aarhus after funeral with too many people.
23. 11-08-2020 – requirement for face masks in municipalities Skanderborg, Silkeborg, Odder, Favrskov and Aarhus.
24. 14-08-2020 – bars and restaurants are allowed have open until 2am, but no new guest after 23pm. Still max gathering of 100 people. Tourists are allowed even if they do not have six overnight stays.
25. 22-08-2020 – requirement of people over age 12 wearing face masks in public transportation, busses and on ferries.
26. 08-09-2020 – special rules for 18 municipalities; København, Odense, Albertslund, Ballerup, Brøndby, Dragør, Frederiksberg, Gentofte, Gladsaxe, Glostrup, Herlev, Hvidovre, Høje–Taastrup, Ishøj, Lyngby–Tårbæk, Rødovre, Tårnby and Vallensbæk. – gathering of more than 50 people are prohibited, and bars and restaurants must close earlier.

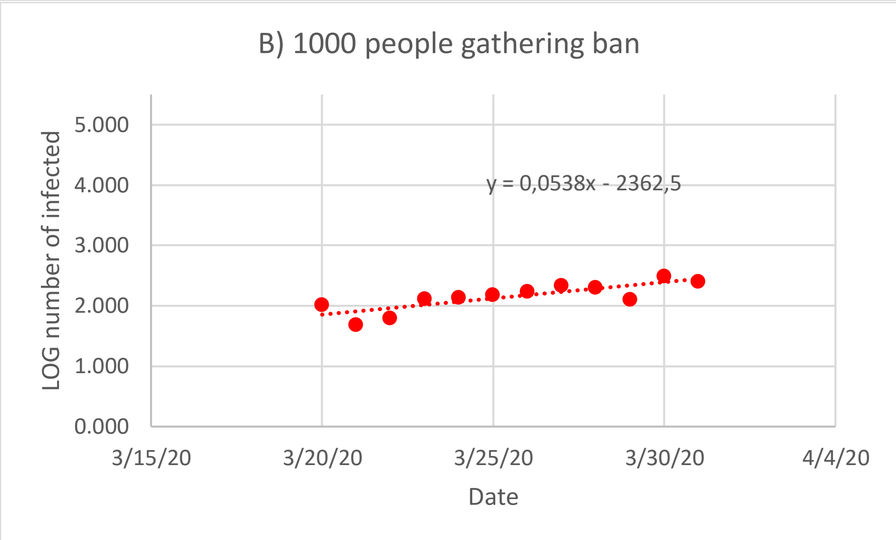
27. 15-09-2020 – more rules to 17 of the 18 municipalities; København, Albertslund, Ballerup, Brøndby, Dragør, Frederiksberg, Gentofte, Gladsaxe, Glostrup, Herlev, Hvidovre, Høje–Taastrup, Ishøj, Lyngby–Tårbæk, Rødovre, Tårnby and Vallensbæk. Permitted to wear face mask or visor at restaurants, cafés and bars and they must close at 10pm. Privat parties are recommended to close at 10pm as well. Max 500 spectators at soccer games.
28. 19-09-2020 – restaurants, cafés and bars must close at 10pm all over the country and face masks at these places are required. Max gathering of 50 people
29. 28-09-2020 – face masks at the doctor's office are required.
30. 07-10-2020 – restrictions from 19-09-2020 are prolonged all over the country for 4 weeks.
31. 26-10-2020 – gatherings of more than 10 people are prohibited until 22-11-2020. Does not count in classroom and at leisure activities. Furthermore, you must now wear a facemask in all indoor public places until 02-01-2021.
32. 05-11-2020 – Northern Jutland closes. Seven municipalities in northern Jutland gets special corona restrictions, due to spread among Minks. People should not leave their own municipality and students from 5-8th grade are homeschooled. Restaurants, fitness, and cinemas are closing, and it is not possible to use public transportation between the seven municipalities until 03-12-2020.
33. 16-11-2020 – Northern Jutland opens again. Students are back in school, and it is possible to travel between the seven municipalities, but not to the rest of Denmark.
34. 20-11-2020 - Gatherings of more than 10 people are being continued and are now prohibited until 13-12-2020.
35. 09-12-2020 – 5th grade and up are being online schooled. Restaurants, bars, cinemas, and theaters are closing until 03-01-2021. These restrictions account for 38 municipalities including Copenhagen, Aarhus, and Odense. Furthermore, the use of face masks in trains and busses are prolonged until 01-03-2021 and max gathering of 10 people are prolonged until 28-02-2021.
36. 10-12-2020 – Restrictions from above now accounts for 69 municipalities.
37. 17-12-2020 – Malls are closing, as well as restaurants and cafes.
38. 21-12-2020 – all liberal professions are closing as well as recreational clubs.
39. 25-12-2020 – all stores except supermarkets and pharmacies are closing. All students are now doing online teaching. These rules accounts until 03-01-2021.
40. 27-12-2020 – First Dane is vaccinated.
41. 29-12-2020 – restrictions from 16-12-2020 is prolonged until 17-01-2021.
42. 05-01-2021 – Max gatherings of 5 people. More distance in supermarkets and public space.
43. 13-01-2021 – Restrictions from 29-12-2020 and 05-01-2021 are prolonged until 07-02-2021.
44. 28-01-2021 – Restrictions from 13-01-2021 are prolonged until 28-02-2021. But students from 0-4th grade are soon allowed to go back to school.
45. 08-02-2021 – 0-4th grade are back in physical school.
46. 01-03-2021 – Outdoor sports activities are opening at a 25 people max capacity. Zoo and amusement parks are allowed to open, a negative test is needed to get access. Smaller stores that are not in malls are allowed to open. On Bornholm all students are getting back to school. In Northern and Western Jutland students in 9th and 10th grade and on boarding schools are going back to school. A recommendation of testing before going back to school is announced and it is recommended to be tested twice a week.

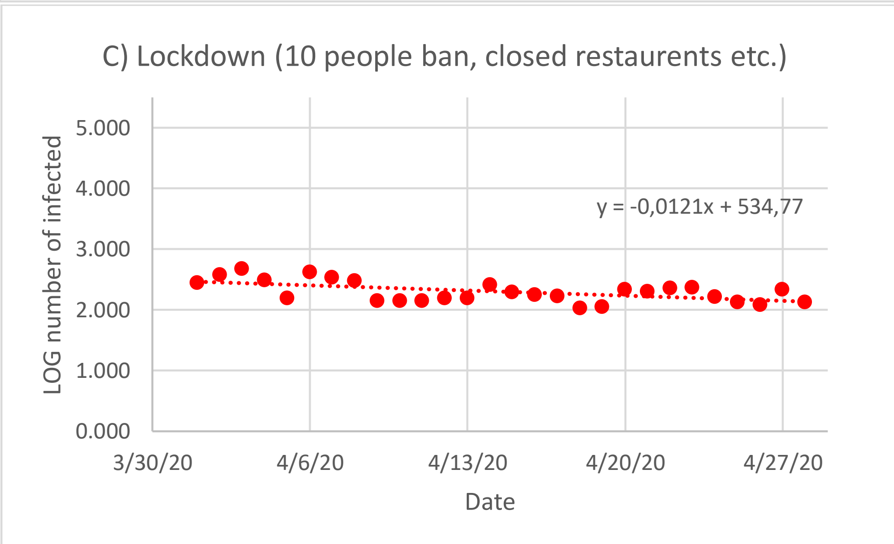
47. 15-03-2021 – boarding school and folk high schools is going back to school. 5-8th grade are allowed once a week for physical school outdoors. All 9th and 10th grade students are back in school excepts in arears around Copenhagen. They can be there half of the time. On small island not connected to mainland by bridge are all students allowed back on full time.

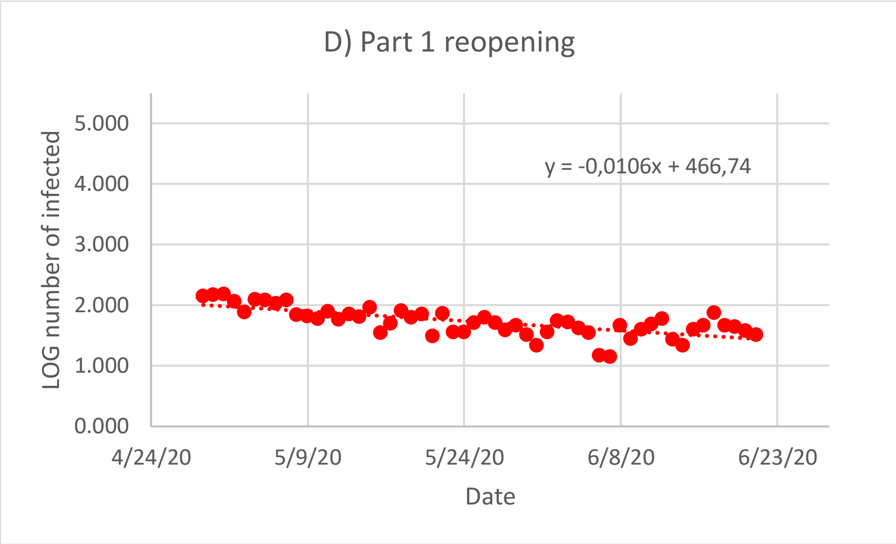
The Danish timeline is constructed based on information provided by official government websites [41], [42], [43] and [44].

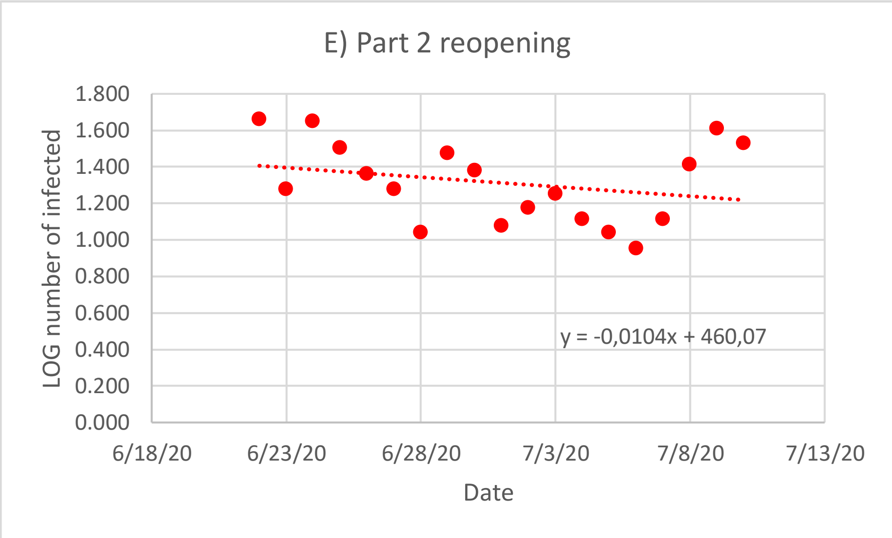
11.3. Appendix 3; Graphs of R_0 from Denmark

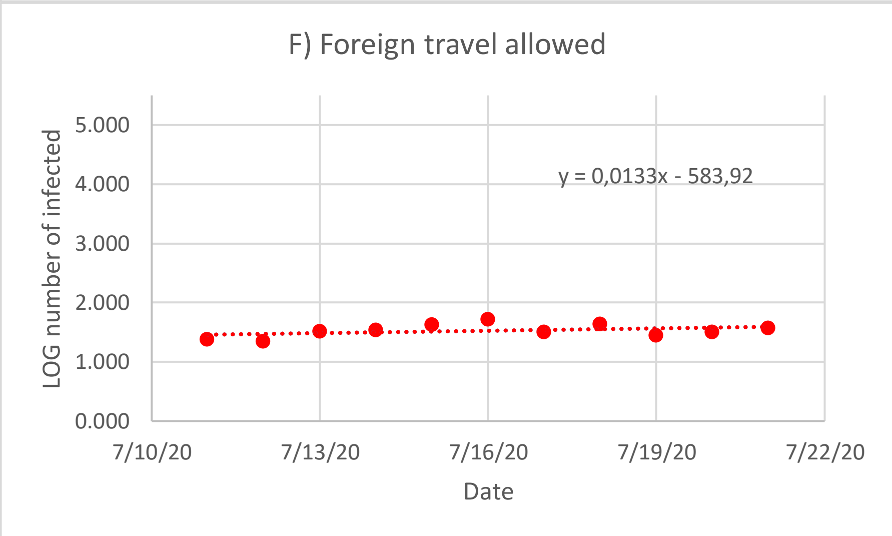


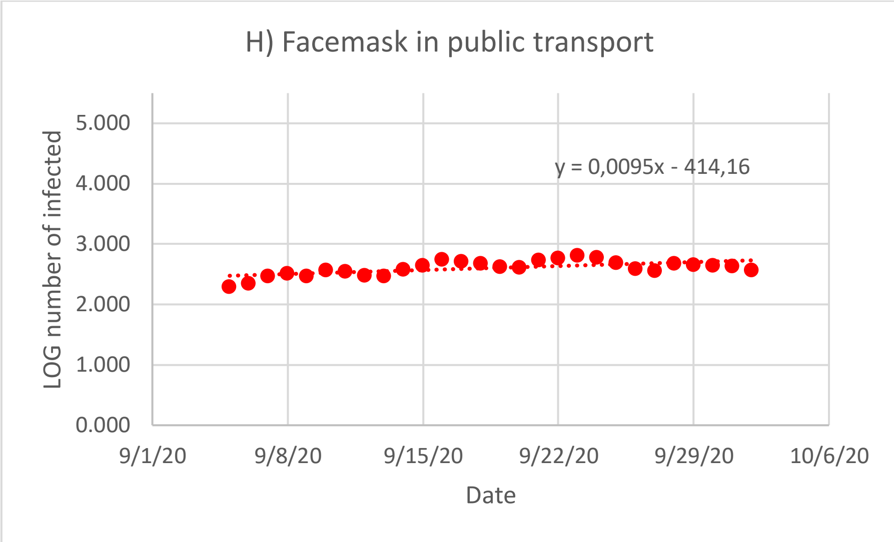


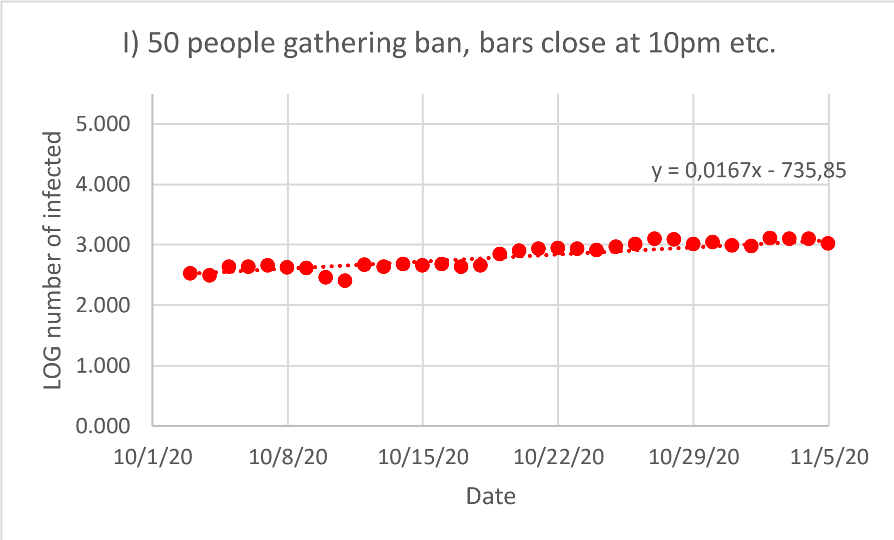


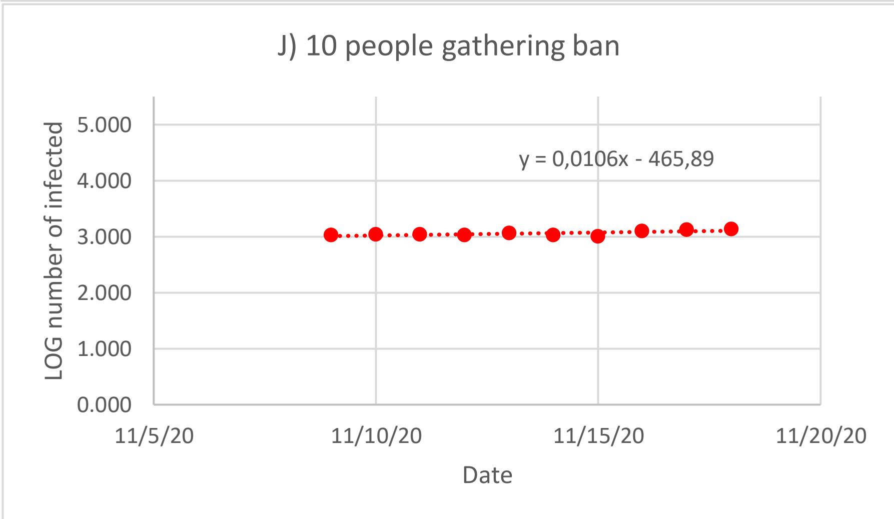

D) Part 1 reopening
y = -0,0106x + 466,74
LOG number of infected
5.000
4.000
3.000
2.000
1.000
0.000
4/24/20
5/9/20
5/24/20
6/8/20
6/23/20
Date

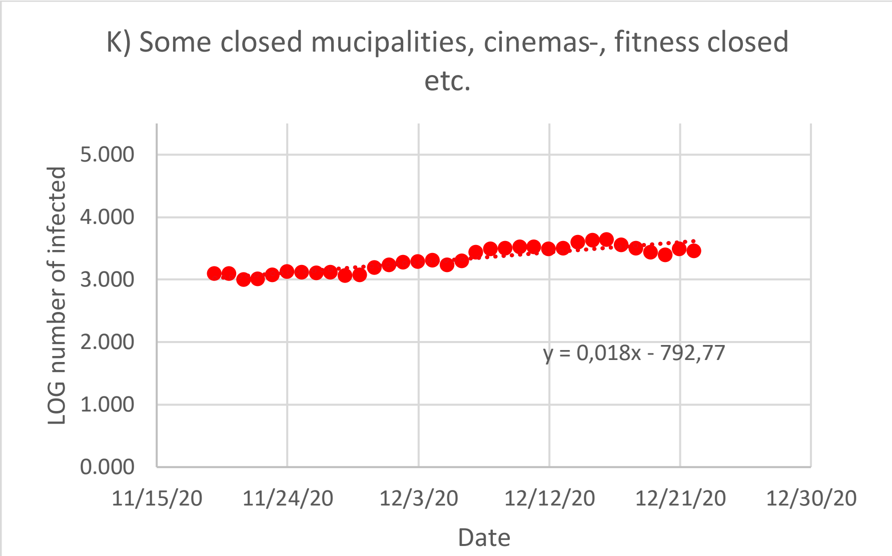

E) Part 2 reopening
LOG number of infected
1.800
1.600
1.400
1.200
1.000
0.800
0.600
0.400
0.200
0.000
y = -0,0104x + 460,07
6/18/20
6/23/20
6/28/20
7/3/20
7/8/20
7/13/20
Date


F) Foreign travel allowed
y = 0,0133x - 583,92
LOG number of infected
5.000
4.000
3.000
2.000
1.000
0.000
7/10/20
7/13/20
7/16/20
7/19/20
7/22/20
Date

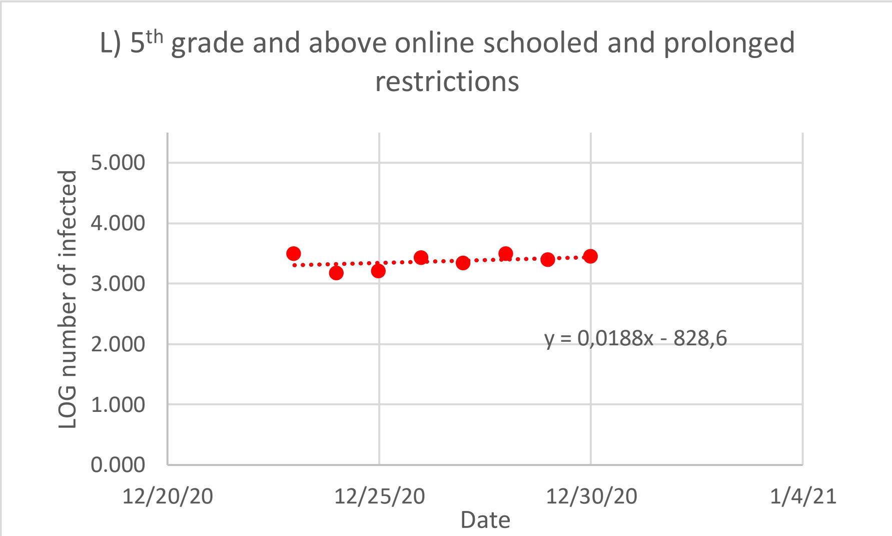

H) Facemask in public transport
y = 0,0095x - 414,16
5.000
4.000
3.000
2.000
1.000
0.000
LOG number of infected
9/1/20
9/8/20
9/15/20
9/22/20
9/29/20
10/6/20
Date


I) 50 people gathering ban, bars close at 10pm etc.
y = 0,0167x - 735,85
5.000
4.000
3.000
2.000
1.000
0.000
LOG number of infected
10/1/20
10/8/20
10/15/20
10/22/20
10/29/20
11/5/20
Date

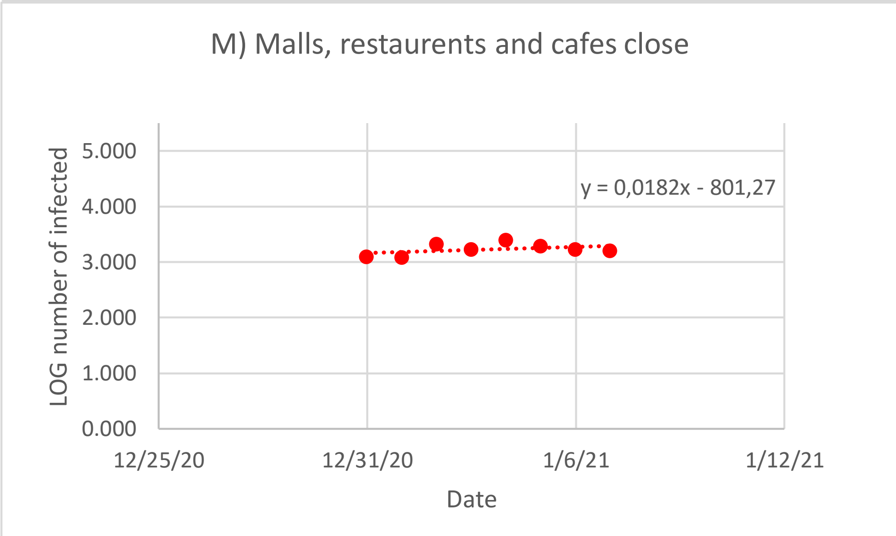

J) 10 people gathering ban
y = 0,0106x - 465,89
5.000
4.000
3.000
2.000
1.000
0.000
LOG number of infected
11/5/20
11/10/20
11/15/20
11/20/20
Date



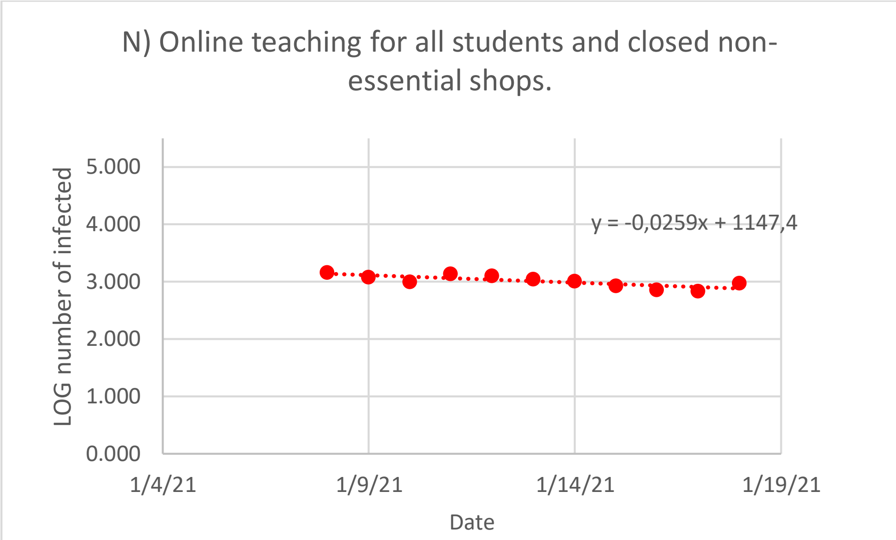
K) Some closed mucipalities, cinemas-, fitness closed etc.
LOG number of infected
5.000
4.000
3.000
2.000
1.000
0.000
y = 0,018x - 792,77
11/15/20
11/24/20
12/3/20
12/12/20
12/21/20
12/30/20
Date

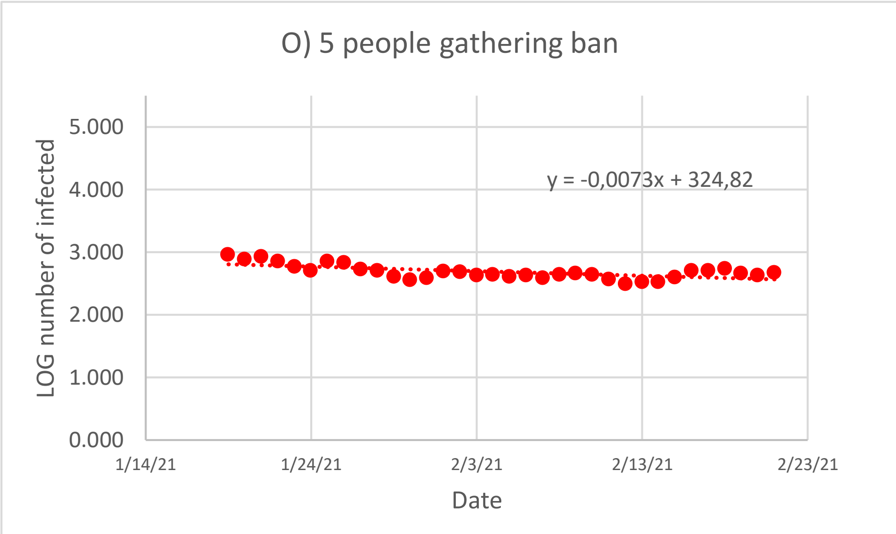


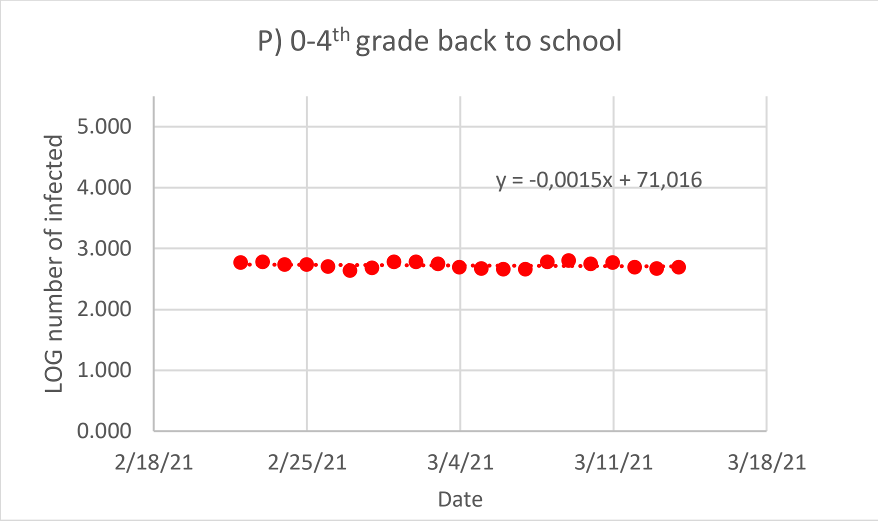
L) 5th grade and above online schooled and prolonged restrictions
LOG number of infected
5.000
4.000
3.000
2.000
1.000
0.000
y = 0,0188x - 828,6
12/20/20
12/25/20
12/30/20
1/4/21
Date



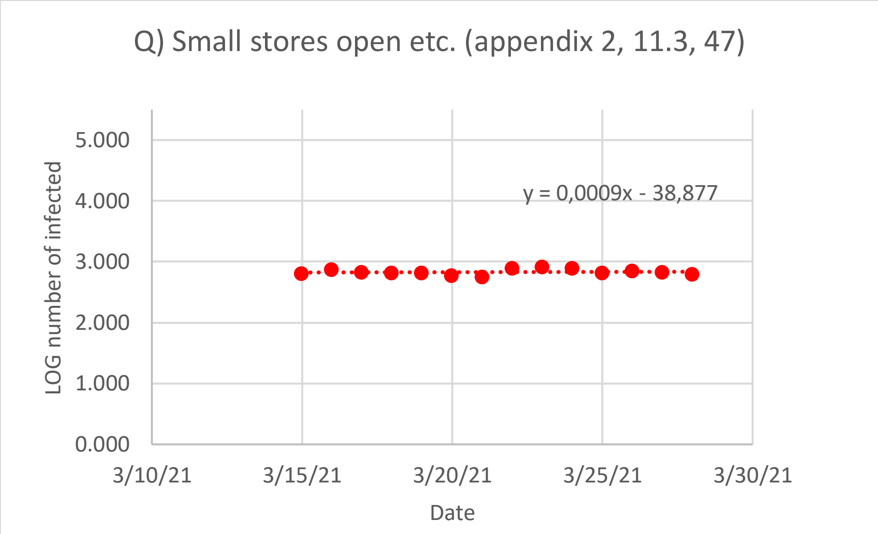
M) Malls, restaurents and cafes close
LOG number of infected
5.000
4.000
3.000
2.000
1.000
0.000
y = 0,0182x - 801,27
12/25/20
12/31/20
1/6/21
1/12/21
Date


N) Online teaching for all students and closed non-essential shops.
LOG number of infected
5.000
4.000
3.000
2.000
1.000
0.000
y = -0,0259x + 1147,4
1/4/21
1/9/21
1/14/21
1/19/21
Date


O) 5 people gathering ban
LOG number of infected
5.000
4.000
3.000
2.000
1.000
0.000
y = -0,0073x + 324,82
1/14/21
1/24/21
2/3/21
2/13/21
2/23/21
Date

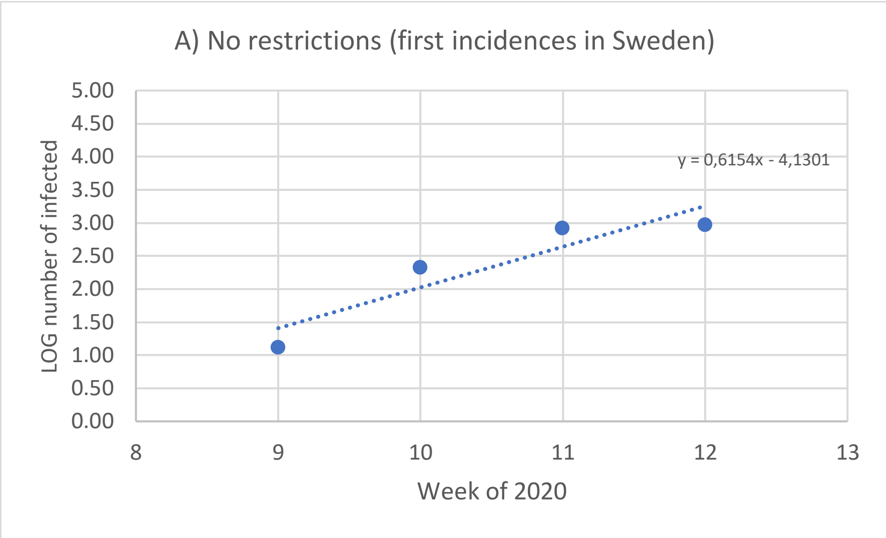


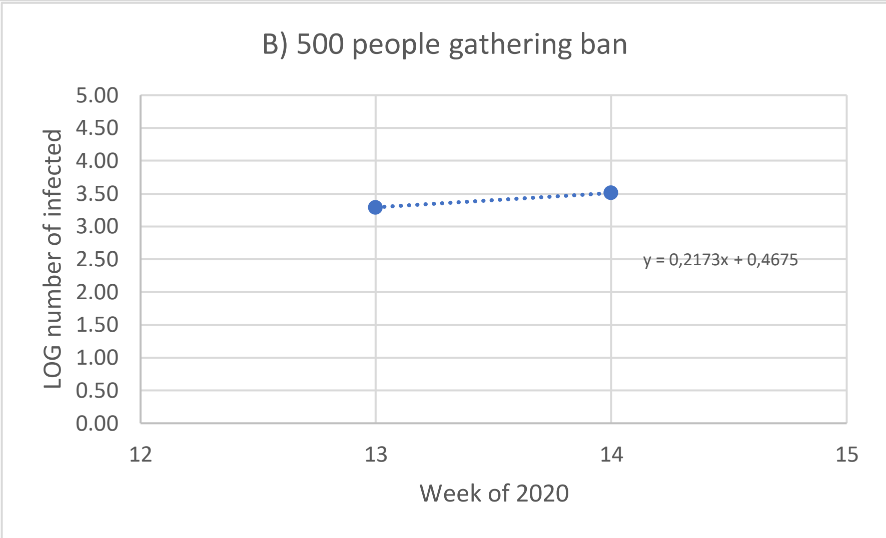
P) 0-4th grade back to school
y = -0,0015x + 71,016
LOG number of infected
5.000
4.000
3.000
2.000
1.000
0.000
2/18/21
2/25/21
3/4/21
3/11/21
3/18/21
Date

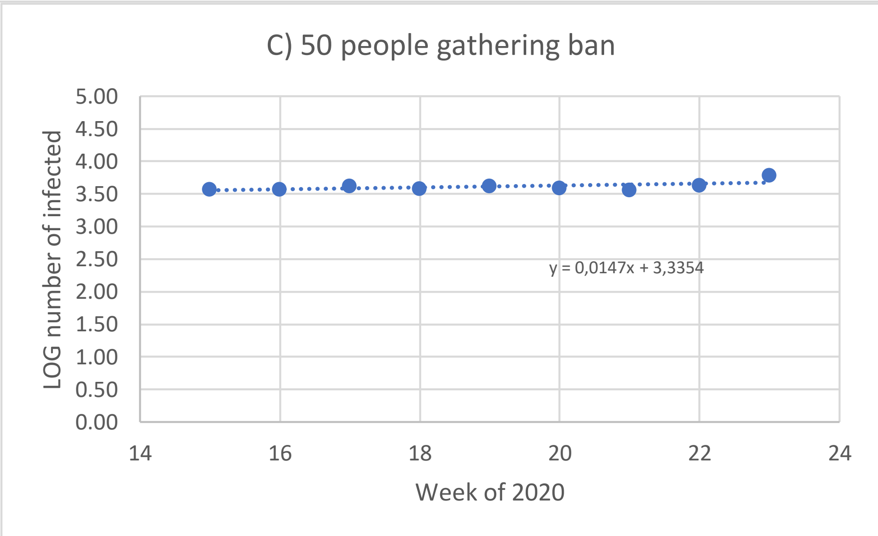


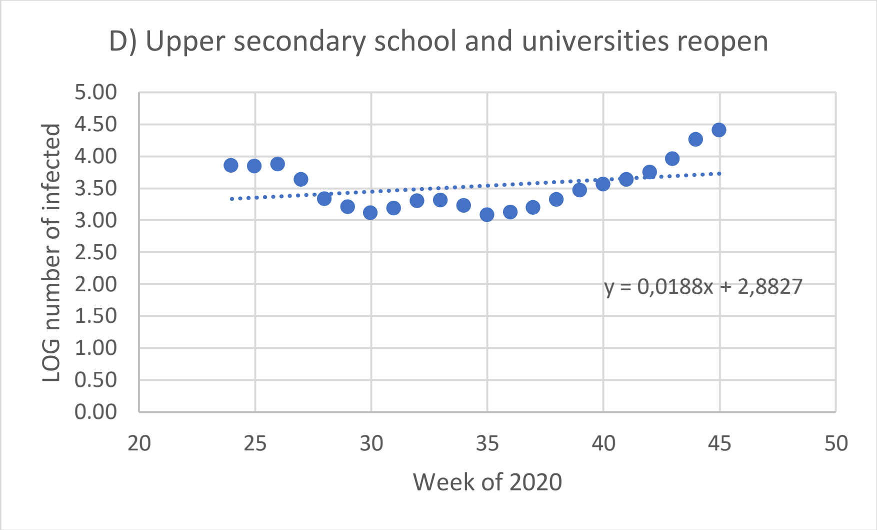
Q) Small stores open etc. (appendix 2, 11.3, 47)
y = 0,0009x - 38,877
LOG number of infected
5.000
4.000
3.000
2.000
1.000
0.000
3/10/21
3/15/21
3/20/21
3/25/21
3/30/21
Date

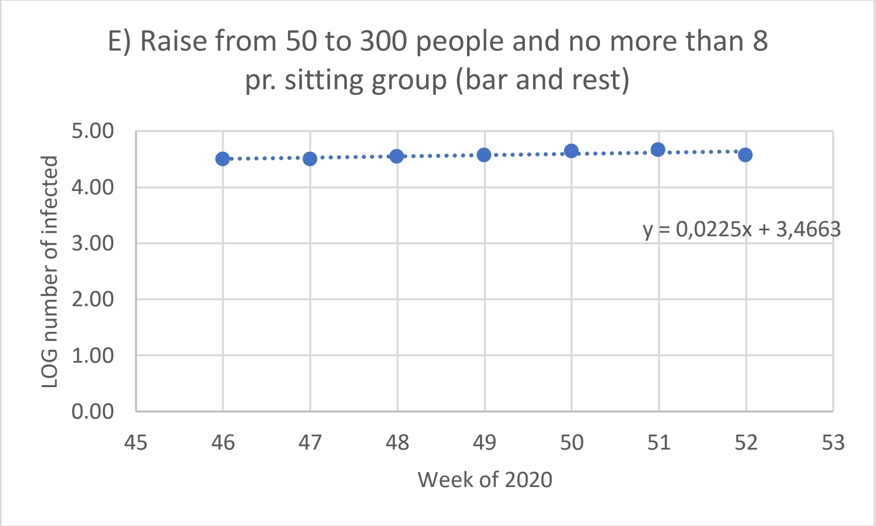
11.4. Appendix 4; Graphs of R_0 from Sweden

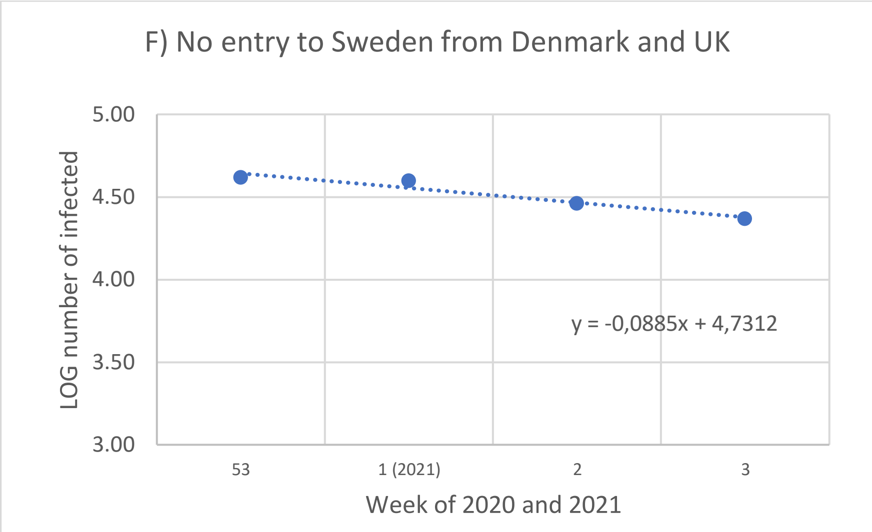


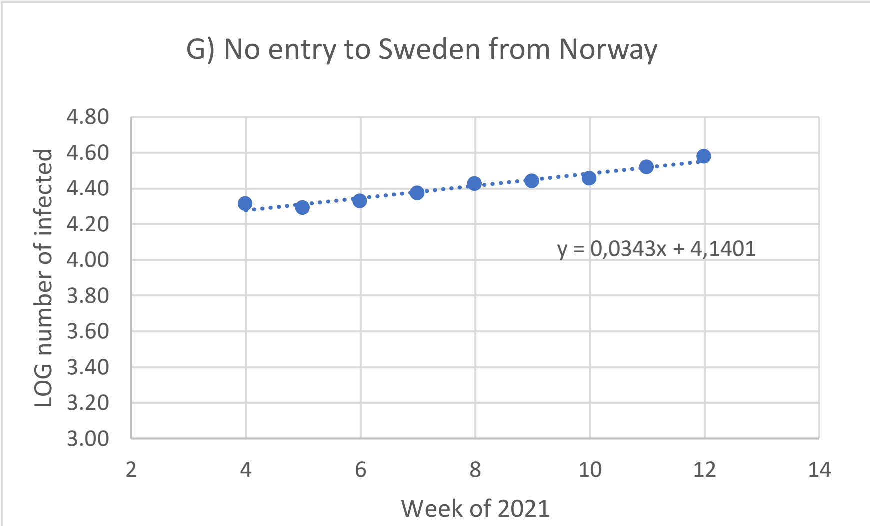





D) Upper secondary school and universities reopen
LOG number of infected
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
20
25
30
35
40
45
50
Week of 2020
y = 0,0188x + 2,8827


E) Raise from 50 to 300 people and no more than 8 pr. sitting group (bar and rest)
LOG number of infected
5.00
4.00
3.00
2.00
1.00
0.00
45
46
47
48
49
50
51
52
53
Week of 2020
y = 0,0225x + 3,4663


F) No entry to Sweden from Denmark and UK
5.00
4.50
4.00
3.50
3.00
LOG number of infected
y = -0,0885x + 4,7312
53
1 (2021)
2
3
Week of 2020 and 2021


G) No entry to Sweden from Norway
4.80
4.60
4.40
4.20
4.00
3.80
3.60
3.40
3.20
3.00
LOG number of infected
y = 0,0343x + 4,1401
2
4
6
8
10
12
14
Week of 2021

11.5. Appendix 5; Output of SIR model from Denmark

```
time (days):  392
total population:  5840094
initial infected:  175
total cases (I+R) at t=  392 :  249166
Recovered at t=   392 :  241742

Infected (infectious) at t=  392 :  7424

Susceptable at t=  392 :  5590928
```

11.6. Appendix 6; Output of the SIR model from Sweden

```
time (days):  399
total population:  10385405
initial infected:  60
total cases (I+R) at t=  399 :  804278
Recovered at t=   399 :  772753

Infected (infectious) at t=  399 :  31525

Susceptable at t=  399 :  9581127
```