COVID-19 prevalence and the effect of mobility regulations

Quantifying the effect of regulations in Italy, the Netherlands and Poland

Jorrim Prins
Universiteit van Amsterdam
11038934

Isabelle Brakenhoff
Universiteit van Amsterdam
11283912

1 INTRODUCTION

In absence of medical answers to the current COVID-19 epidemic, human behaviour is key to contain the spread of the virus [4]. The major approach of policymakers and health experts has been the adoption of strict rules to decrease individual mobility and increase social distancing accompanied by strict hygiene and the use of masks and gloves [7]. The public health measures presumably reduce transmission, but it is near impossible to say to what extent they contribute to the containment of an outbreak [6]. We therefore focus on evaluating the effect of the measures focusing on social distancing, also referred to as lockdowns. Real-time detection of pattern changes are essential to evaluate the current measures of control and design future ones [5]. The effectiveness of containment policies has been increasingly studied over the past months. For example, Vinceti et al. [6] provide evidence that the intended effects of the mobility restrictions adopted in Italy (IT) to counteract spread of the COVID-19 virus were generally seen within 14 to 18 days after the implementation of tight lockdown measures. In the areas with the highest prevalence of the disease, the effect of regulations was seen as early as 9 days after implementation. This implies a varying lag between imposing decreased mobility measures and slowing person-to-person disease transmission.

As countries in Europe have handled the pandemic by their own individual schedule of measures, it is interesting to investigate the effectiveness of disease limitation in multiple European countries and compare the various strategies. We focus on IT as the disease emergence in Europe started here and compare it to two other countries that have had varying progress of the disease: the Netherlands (NL) experienced a similar path to IT with a slight delay, but never implemented a complete lockdown in contrast. Poland (PL) was one of the later countries to encounter the first infection with COVID-19 but was very early with their initial regulations. They have slowly increased measures to the point of a complete lockdown. This evaluation could help specifying a coordinated European lockdown strategy, which Ruktanonchai et al. [3] prove to be significantly more effective at reducing transmission due to the highly connected structure of countries in Europe.

We start this report by focusing on the implemented strategies to prevent the spread of COVID-19 for all three countries and define a SIR-D model to use for analysis. Observed data on the disease is used to fit this SIR-D model for the various phases of the disease and the transmission rates in various stages are compared to the measures in these phases. Various future scenarios are specified and compared to try and answer the following research question: Can the effect of previous lockdown regulations be quantified and used to define strategies for the future?

2 COVID-19 REGULATIONS

Table 1 provides an overview of the measures most focused on limiting the mobility, taken by the government of IT, NL and PL respectively. As expected, we see differences between the approach of the countries in terms of timing and strictness. IT was the the first European country to encounter a COVID-19 infection, soon followed by NL. After a period of soft lockdown, IT responded with a complete lockdown and closing the borders. NL chose for an 'intelligent' lockdown a week later, limiting the restrictions to a certain level and the government calling on the internal motivation of the population. The first COVID-19 infection in PL was observed 1,5 week after the first infection in IT, it gave the government of PL the time to accept an emergency law and impose strict rules to prevent the virus from spreading before it appeared. Also, the population of PL was already aware of the severity of the virus and started limiting their movements. Less than two weeks after the first infection, the government closed the borders and imposed stricter regulations until a complete lockdown on April 1st.

Shops and business reopen quite early in NL, followed by IT. PL remains in its strict lockdown until a later point of the summer. Official ending of the lockdowns in each country occurs in early- to mid-June, however several limitations stayed in place afterwards (e.g. large events remain prohibited and clubs remain closed). The number of infections has started to increase in all three countries since the end of the summer and new regulations have therefore come into play in the past couple of weeks. We observe the three countries under investigation in roughly the same state of regulations, all in some kind of partial lockdown since the beginning of October.

3 SIR-D MODEL

The observed data we use to try and estimate the effect of several measures on the spread of COVID-19 will be fitted to a non-demographic SIR-type compartment model with an extra state of being diseased. This SIR-D model contains three important parameters in the rate of transmission ρ, the recovery rate σ and the mortality rate κ. We will not focus on the mortality rate and barely focus on the recovery rate, so most focus will be on ρ. These parameters influence the flow between the four compartments through the ODE's we implement:

$$\frac{dS}{dt} = -\rho SI \tag{1}$$

$$\frac{dI}{dt} = \rho SI - (\sigma + \kappa)I \tag{2}$$

$$\frac{dR}{dt} = \sigma I \tag{3}$$

$$\frac{dD}{dt} = \kappa I \tag{4}$$

Table 1: Overview of measures taken by Italy, Netherlands and Poland during the COVID-19 pandemic

	IT	NL	PL
20/02	First infection		
23/02	Soft lockdown, stricter regional lockdown		
27/02		First infection	
02/03			Emergency law
04/03			First infection
09/03	Complete lockdown, borders close		
10/03			Gatherings <1000 outside, <500 inside
12/03		No events, work from home, gatherings <100	
15/03		Schools close	Borders close, gatherings <50
23/03		Intelligent lockdown	
25/03			Almost complete lockdown
01/04			Complete lockdown
14/04	Small shops open		
20/04			Recreational movement allowed
04/05	Factories open, municipal movement allowed		
11/05		Primary Schools open	
18/05	Businesses reopen, regional movement allowed		
01/06		Restaurants and high school partly open	
03/06	End lockdown, borders open		
13/06			End lockdown, borders open
01/07		Small events allowed	
01/09		Schools open	
03/10	Regional measures		
10/10			Partial lockdown
14/10		Partial lockdown	

4 EXPETIMENTAL SETUP

We provide a set of experiments to explore the effects of several COVID-19-related measures that have been implemented in the past months. Data on infections, confirmations and deaths are provided by Guidotti and Ardia [2] for many countries, we use the available data for the Italy (IT), Netherlands (NL) and Poland (PL) starting from the moment they are reported. Note that the starting moment of infection presence varies over countries, we start from the earliest moment to capture the complete disease dynamics over the past months. Data on IT is available from February 24th, NL from March 24th and PL from March 16th, an overview of the number of infected and deceased individuals is provided in Figure 1. Differences between the dynamics per country are obvious, so a detailed analysis of disease development should be performed to gain more insight.

To analyze the disease dynamics for the varying periods of regulations in each country, we use the *CovsirPhy* package by CovsirPhy-Development-Team [1]. It offers SIR-D, SIR-F and SEWIR-F models. They also implement a Susceptible-Recovered trend analysis to identify phases within the spread of COVID-19, allowing parameters to vary between phases. Parameters are estimated per phase by minimizing the Root Mean Squared Log Error (RMSLE) and we choose to do this on a SIR-D model (regular SIR with an extra state of deceased individuals). Significant changes in the *effective contact rate* or *transmission rate* ρ can hopefully be observed corresponding to the implemented lockdown regulations over time, so the consequences of varying regulations can be compared.

Although the effect of past regulations can be informative, more insight into future developments is of major importance to policy makers. We will perform scenario analysis from the current situation in all three countries, specifying scenarios under varying regulations, with some retrospect to previous months and with an hypothetical available medicine. The primary scenario is defined as the *Main* scenario, presenting future dynamics based on the current parameter values of the model. As the number of COVID-19 infections has again been rising over the past couple of weeks, this scenario is not likely to be very plausible. Regulations are or will most likely be implemented to prevent further spread of the disease, we therefore define a *Lockdown* and *Semi-Lockdown (Semi-LD)* scenario. The *Lockdown* scenario has an adjusted value for ρ, corresponding to the lowest estimated value of ρ the specific country has obtained in the past. We assume that this is the ρ value corresponding to the most strict lockdown regulations in a country. In addition, we specify the *Semi-LD* scenario by doubling the ρ value from the *Lockdown* scenario, representing a situation where a somewhat less strict regime is maintained. We implement these scenarios as if regulations would start today and their effects can be observed starting a month from now.

Since most countries have experienced an increase in infections since September 1st, we provide a *Retro(spective)* scenario. This scenario uses the parameters that are estimated for the phase that September 1st falls in for each country. It could provide insight into the dynamics we would have experienced if regulations or actions had not changed since the end of the summer holidays (for children and students).

Although medical solutions to the current pandemic, such as a vaccination or medicine, are still predominantly speculative, it is interesting to hypothesize the effects they would have. Vaccination strategies are beyond the scope of this research, but we can investigate the effect of a possible medicine. We specify a scenario as *Medicine*, assuming a medicine is developed that decreases the recovery time by 2, thereby increasing the *recovery rate* σ by 2. It can be interesting to compare the effect of changing recovery dynamics to changing spreading dynamics.

As the most common goal of COVID-19 regulations is prevention of an epidemic, we look at the target value for R_0, that should be below 1. Assuming a recovery and mortality rate equal to their current value, we estimate the transmission rate that regulations should achieve to prevent an epidemic from happening. This transmission rate can be compared to the transmission rates resulting from the other scenarios to put the effect of the regulations into perspective.

Simulation of the scenarios described above is performed from the point that observed data ends until April 2022. For the *Medicine* and *Target* scenarios this means that parameter settings are kept equal from current time onward, the *Retro* scenario keeps parameters constant from September 1st and both lockdown scenarios assume implementation at current time and effects in 30 days.

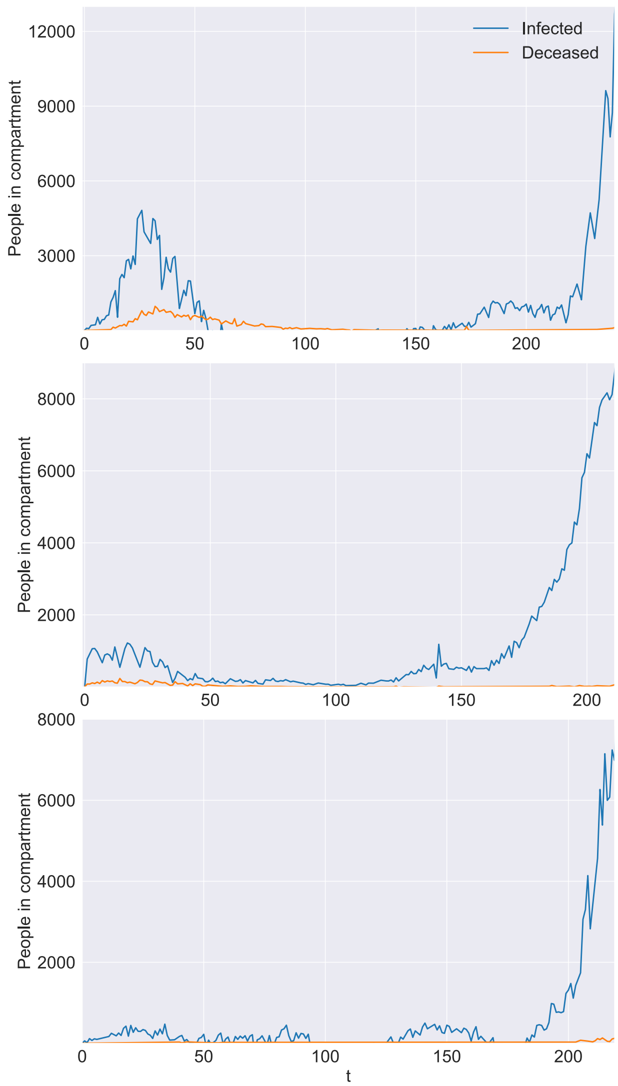

Figure 1: Overview of disease dynamics since introduction
From top to bottom: Italy, Netherlands & Poland

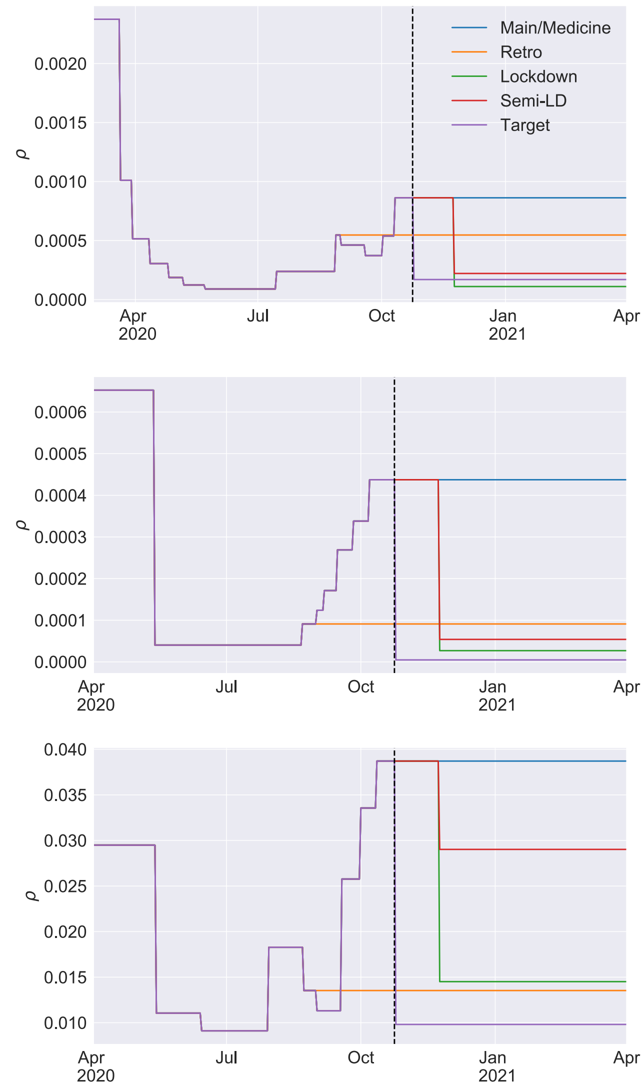

Figure 2: Development of ρ for varying phases and scenarios
From top to bottom: Italy, Netherlands & Poland. Black dotted line is today, October 24th 2020.

5 RESULTS

We will initially look at the development of the transmission rate ρ over the defined phases and projections, trying to couple the fluctuations of this rate to the the implemented government regulations. Projections for the number of infections over time are subsequently shown to observe the expected effect of the specified scenarios.

Figure 2 presents the transmission rates for every phase for IT, NL and PL respectively, we match these to the specified dates in Table 1. Note that rates from the past are all equal as the scenarios only hold for future simulations.

IT was one of the countries with the earliest infections in Europe, showing its first infection on February 20th. A soft lockdown was originally implemented on February 23th and extended to a complete lockdown on March 9th. As regulations need approximately 14 to 18 days to show their effect, we can link these lockdown regulations to the large drop of ρ at the end of March (top plot in Figure 2). Regulations were softened over the following months until the lockdown ended on June 3rd. From July, a month later, we can see the transmission rate increasing again until today, indicated by the dotted black line. IT has implemented regional measures in the beginning of October, results of these measures can not yet be observed in this data.

NL had its initial infection a week after IT, and implemented an intelligent lockdown halfway through March. The large drop of ρ can however only be observed with a significant delay of approximately 6 weeks. It could be explained by the availability of data starting at the end of March, biasing the phase-analysis of the early stages. Relaxations of measures take place on the first of June, July and September, vastly increasing rates can be observed from September as a result. The partial lockdown from October 14th has not shown its effects yet as expected. PL was late observing its first infection, only in the beginning of March. They implement increasing measures until a complete lockdown on April 1st, corresponding the the drop of ρ that can be observed about six weeks later in the bottom plot of Figure 2. Their lockdown ends halfway through June and ρ starts increasing from August again, with an exception of one phase in September. As PL was fast with their first lockdown, the transmission rate is currently estimated to be

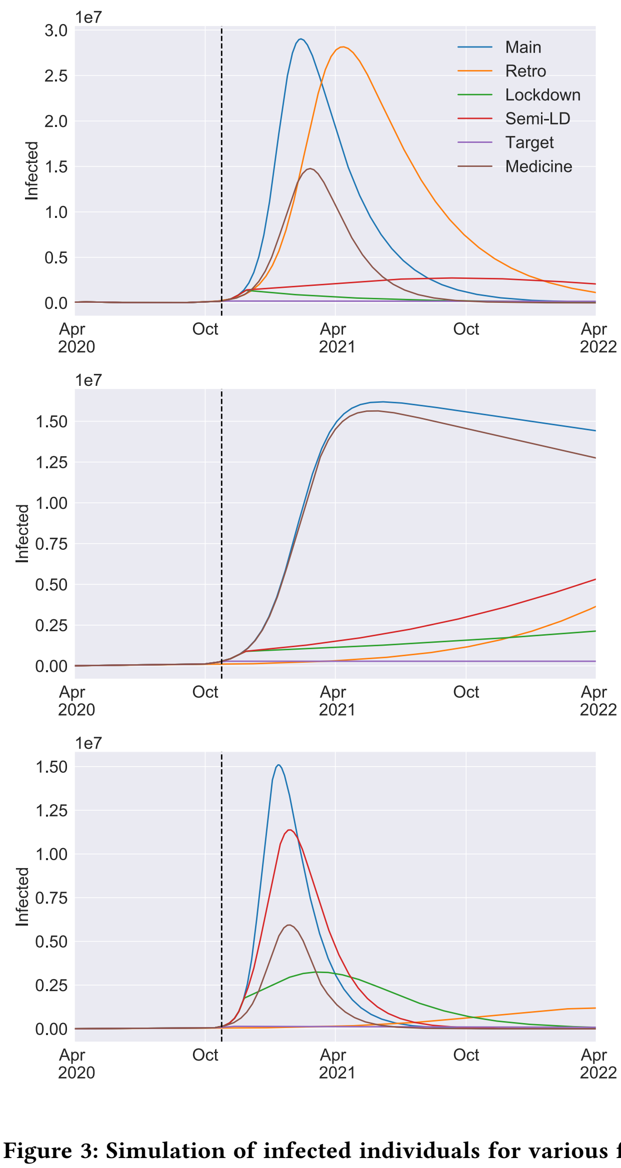

Figure 3: Simulation of infected individuals for various future scenarios

From top to bottom: Italy, Netherlands & Poland. Black dotted line is today, October 24th 2020.

higher then it was in April. The effects of PL's partial lockdown that started on October 10th can again not be observed yet as expected.

Looking at the provided scenarios and the transmission rates they assume for the future, note that the *Main* and *Medicine* scenarios always have the same rate, as adjustments are only made to σ in this scenario. For all three countries, looking at the *Retro* scenario shows that behavioral changes over the past couple of weeks have deteriorated the situation. The simulations suggest that a complete lockdown would reduce ρ to below the target that prevents an epidemic for IT, a semi-lockdown would not be enough to reach this goal. The data for the other two countries are more worrying, as even the strictest lockdown measures from the past are expected to lower ρ to a level that is still above the target.

Simulations of the number of infected individuals over time can be found in Figure 3 for the specified scenarios. The current scenario, as well as the retrospective scenario, are extremely worrying for IT and reach a peak of almost 30 million infections in February and April next year.[1] A hypothetical medicine would decrease this peak for spring 2021 by half, only caused by an increased recovery rate. A lockdown and semi-lockdown would cause a peak of infections of 1.4 and 2.7 million respectively, the peak for the lockdown scenario is caused by the 30 day delay of the effects thereof.

NL was in a somewhat more stable situation than IT in September, as the retrospective scenario is not as bad as the current one. The recovery rate in NL is however estimated to be very low, causing the peak of the scenario with a hypothetical medicine to be almost as high as the current scenario. Slow recovery from this peak is also the cause of the low estimated value for σ. The high peaks for the current and *Medicine* scenario would mean an almost completely infected Dutch population. Lockdown and semi-lockdown scenarios help slow down the exponential increase from the current point in time, but still end up with enormous amounts of infected individuals before April 2022 (that keep increasing afterwards).

As for IT and NL, the current scenario for PL is estimated to be the worst, causing an infection peak of 15 million individuals by Januari 2021. The previous lockdown measures that PL has taken seem to have far from enough effect on the transmission rate to keep the peak low, as the lockdown scenario still has a significant peak in the spring of 2021 of 3.2 million infected individuals. The hypothetical medicine has a similar effect as it has on IT, lowering the peak to about half its size. PL would optimally go back to their situation from the beginning of September, as the number of infected individuals develops very slowly from the retrospective estimates.

The *Target* scenario obviously does not represent an infection peak for any of the countries, as it is estimated to be equal to an R_0 of 1.0. An overview of the R_0 values in the specified scenarios for every country can be found in Table 2. The lockdown scenario in IT is the only scenario with an R_0 below 1. The values for NL are unrealistically high in some scenarios.

[1] Note that this is half of IT's complete population.

Table 2: R_0 for future scenarios for IT, NL and PL

	Main	Retro	LD	Semi-LD	Target	Med.
IT	5.07	4.86	0.65	1.30	1.00	2.58
NL	92.53	11.63	5.71	11.42	1.00	54.46
PL	3.95	1.31	1.48	2.96	1.00	2.02

6 CONCLUSION

We observe data on COVID-19 infections an fit this data to a SIR-D model to analyze the effect that lockdown regulations have on the prevalence of the disease. Three European countries in Italy, the Netherlands and Poland, each with different disease and regulation development, are used to quantify the effect of their regulations and the impact they could have on the current situation in each country. The estimated rate of transmission for every country seems to match the implemented regulations, with a decrease under lockdown measures and an increase under relaxation thereof. Several future scenarios are specified an simulated, based on the relative effect the first lockdown had on the rate of transmission or the hypothetical effect of a medicine. The data suggests that the current situation for all countries is worse than it was at the beginning of September. Previous regulations would only be enough to prevent an outbreak in Italy and are not enough for the Netherlands and Poland, so we conclude the Italian lockdown strategy to be most effective.

Improvements could be made by gathering more plausible data from the Netherlands, which presents results that are out of proportion in some cases. Further research should also focus on different model specifications with varying complexity (SEIR, SIS, SEWIR-F) or perform similar analysis on the mortality and recovery rate as we have done with the transmission rate. Since we have focused mostly on mobility regulations, the health care regulation are left for future research as well. Additionally, to put together a single strategy for the complete continent of Europe, more European countries (and maybe even countries from other continents) have to be analyzed in a similar way to provide a wider spectrum.

REFERENCES

[1] CovsirPhy-Development-Team. Covsirphy, python package for covid-19 analysis with sir-derived ode models, 2020. URL https://github.com/lisphilar/covid19-sir.

[2] E. Guidotti and D. Ardia. Covid-19 data hub. *Journal of Open Source Software*, 5 (51):2376, 2020.

[3] N. W. Ruktanonchai, J. Floyd, S. Lai, C. W. Ruktanonchai, A. Sadilek, P. Rente-Lourenco, X. Ben, A. Carioli, J. Gwinn, J. Steele, et al. Assessing the impact of coordinated covid-19 exit strategies across europe. *Science*, 369(6510):1465–1470, 2020.

[4] U. Social and B. S. to support Covid-19 Pandemci Response. C. *Nature Human Behaviour*, pages 1–12, 2020.

[5] A. Tobías. Evaluation of the lockdowns for the sars-cov-2 epidemic in italy and spain after one month follow up. *Science of the Total Environment*, 725(138539), 2020.

[6] M. Vinceti, T. Filippini, K. J. Rothman, F. Ferrari, A. Goffi, G. Maffeis, and N. Orsini. Lockdown timing and efficacy in controlling covid-19 using mobile phone tracking. *EClinicalMedicine*, 25:100457, 2020.

[7] WHO. Coronavirus disease (covid-19) advice for the public, 2020. URL https://www.who.int/emergencies/diseases/novel-coronavirus-2019/advice-for-public.