Misleading Biases in Covid Incidence

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Abstract

For most of the Covid Pandemic, the German contact regulations were strictly tied to the Incidence Statistic with equal thresholds for all regions. This paper unveils three major biases associated with this strategy. To this end we assume that an appropriate measure should be predictive for future Intensive Care Unit (ICU) Occupancy. While the Incidence provides a rough real time estimate, it needs to be complemented by the Positive Testing Rate, Vaccination Statistics and the Current Intensive Care Unit Occupancy to serve as an appropriate index for pandemic severity.

1 Introduction

In Germany, the former law for contact regulation (Infektionsschutzgesetz) tied lockdown measures directly to the number of new confirmed infections per 100,000 inhabitants in a particular region averaged over seven days [1]. We refer to this statistic as *Incidence* in the following.

Since the primary objective of lockdown regulations is to ensure a functioning health care system, policies should focus on minimizing the risk of exhausting hospital capacities.

The following data analysis demonstrates that case numbers alone can not measure the pandemic severity exhaustively. Even before vaccination played a role, they should have been complemented by testing and hospitalization statistics to derive policies which ensure a fully operational health care system. Even during the current debate, the leading German Institute for Infectious Diseases (Robert Koch Institute) recommends to tie lockdown measures to the Incidence [7].

Section 2 unveils three major biases in Incidence data which misguide lockdown decisions. The subsequent section illustrates that even accounting for the non trivial testing strategy bias is possible with the data at hand. Furthermore we address the social and ethical challenges associated with building a predictive model for Pandemic Management.

1.1 Data

The analyzed data set [3], [5] was collected by Our World in Data from different sources. Including daily raw data on Cases, Deaths, Vaccinations, Hospitalization and Tests for 231 countries, it is the most exhaustive publicly accessible Covid data set Additionally it contains socio-economic information (e.g. demographic structure and economic indices), policy responses as well as estimates for reproduction rates. Thorough documentation [1] and an interactive explorer [2] are available.

Each positive case refers to a positive PCR test. As Hospitalization Data is only available for some western countries, we focus on European States. The full Python Code as well as the data up until 28^{th} of September 2021 can be found at GitHub.[3].

[1] https://github.com/owid/covid-19-data/tree/master/public/data
[2] https://ourworldindata.org/coronavirus-data-explorer
[3] https://github.com/pat-rig/Mlockdown

2 Biases

After arguing that local thresholds are necessary to account for regionally varying Intensive Care Unit (ICU) capacities, we demonstrate that Incidence depends on the testing strategy. Furthermore, we will see that the actual consequences of high Incidence depend on the current ICU occupancy. Finally, we show that vaccination requires us to adjust the Incidence for more than only one effect.

2.1 Regional Variabilities in ICU Capacity and Testing

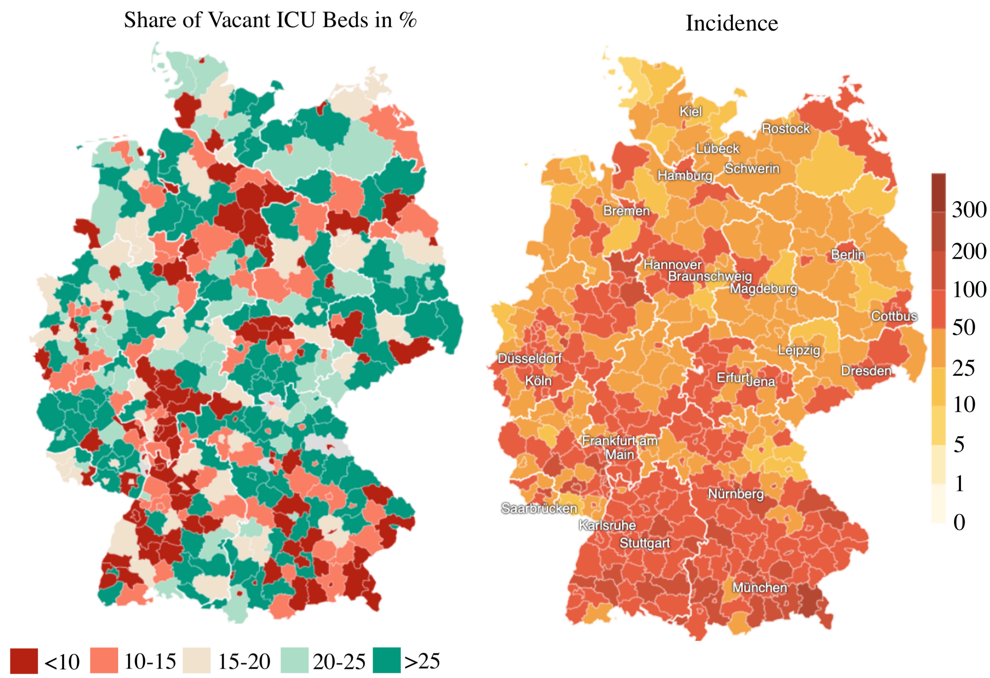

Figure 1: German Pandemic Situation on 27^{th} September 2021. Share of Available ICU Beds (from https://intensivregister.de) and Incidence per Landkreis (modified from https://corona.rki.de).

The thresholds for lockdown measures are the same for each Landkreis, even though testing strategies and ICU capacities vary strongly.

For instance, the State of Saarland has around 50 Intensive Care Unit (ICU) beds per 100,000 inhabitants, whereas Brandenburg only has 25 [8]. The consequnce is reflected in Figure 1, which shows ICU Capacity (left) and Incidence (right) per Landkreis on the 27^{th} September 2021. We observe that high Incidence regions are not always associated with low ICU capacity (e.g. the Southern Center between Stuttgart and München, near Dresden and around Nürnberg). More importantly there is a cluster of regions in the Northern Center (slightly SE of Hamburg) with relatively low Incidence between 25 and 50 but very low ICU capacity (less than 10% vacant beds) as well.

Even though the German contact regulations are defined per Landkreis, testing data is not collected on that scale [6]. The following subsection demonstrates that this data is important.

2.2 Incidence Depends on Testing Strategy

Prior to the current debate on Incidence as the sole indicator for lockdown measures, politicians argued that Case Numbers are representative for hospitalization rates. While this is true for constant testing rates, a change in testing strategy might influence the Case Numbers strongly without an actual change in the pandemic situation.

Pandemic severity measures should capture the risk of exponential explosion in infections. This risk depends on the fraction of infected people in the population, i.e. the amount of positive cases relative to the number of tested people. In particular this is not equal to the absolute count of positive test results per 100,000. Hence, temporal and spatial variability in testing introduce bias into the Incidence statistic, when used as an estimate of pandemic severity.

Assume an equal Incidence of 200 for two regions. Let 5% of all test results in region A be positive, i.e. a Positive Rate of 0.05. Region B exhibits a positive rate of 0.2. We're ought to conclude that the infection level is more severe for region B. As the 200 positive tests per 100,000 inhabitants (averaged over 7 days) make up a larger fraction of the tested population, we can assume that the a randomly tested person within population B is positive with higher probability than in region A.

2.2.1 Testing Strategies Vary Across Waves and Countries

Figure 2 illustrates the testing strategies for Germany and Israel. It shows the relationship between the Positive Rate and the Incidence. Each point represents one week for Germany and one day for Israel, while each colour represents one wave of infections. The start and end points of the waves were defined individually on the basis of the Incidence curves, such that each wave encompasses the whole upward and downward trend.

In fact we observe varying Positive Rates for equal Incidences within the same country. During the second wave, a Germany wide Incidence of 205 was associated with 8.5% positive test results in one week, whereas a slightly higher Incidence of 210 was measured with roughly 16% of positive tests in another week.

For both countries, we observe a positive linear relationship between Incidence and Positive Rate. The character of the association varies across waves, reflecting differing test strategies.

Incidences were relatively low (below 50) for both countries during the first wave, while the Positive Rate varies strongly up until 10%. In Israel, we observe decreasing slopes for each wave. The lower positive rates for the same Incidences imply either an increase in testing or a less specific testing strategy. Indeed, the peak number of tests increases from wave to wave in Israel, as we can read off Table 1. Consequently, the Incidence should not be compared in between waves without accounting for the Positive Rate.

The slope of the imaginary least-squares lines (for each wave) indicate the strength of the current testing strategies' bias. As the Positive Rate increases faster during the first wave, we conclude that for one detected case there are more undetected cases as in the subsequent waves. Thus, the location of the blue dots, reflect that the Incidence underestimates pandemic severity the strongest for the first wave.

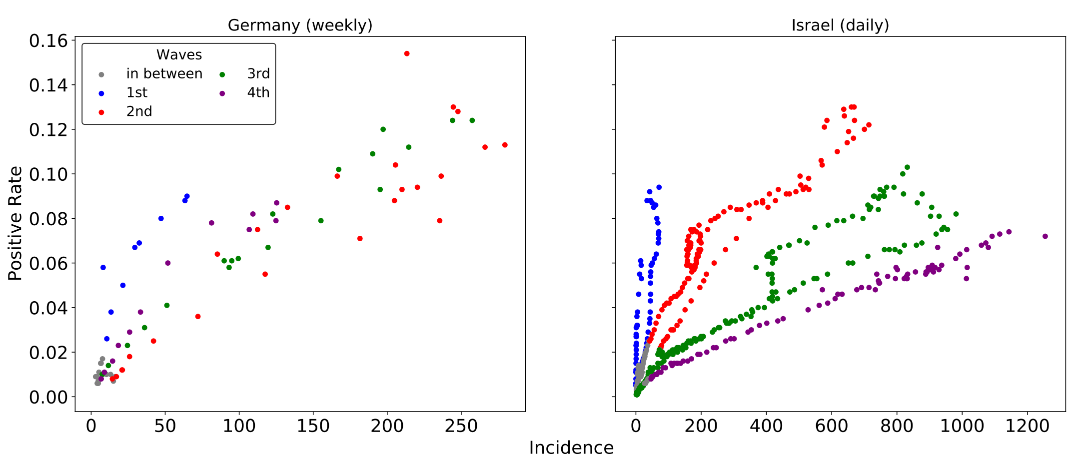

Figure 2: Positive Rate against Incidence for Germany and Israel

Denmark, the only European country, which suffered only two waves so far, is also the only European country with a mostly constant Positive Rate of below 2% (s. Figure 7). Maier [4] evaluates in more detail that this testing strategy was key to Denmark's successful pandemic management.

In conclusion, testing strategies influence the interpretation of Case Statistics. Incidence is not expressive without the Positive Rate. The Positive Rate can serve as a correction for the bias in Incidence introduced by testing intensity but also as an objective metric for adjusting testing policies. Striving for constantly low Positive Rates by means of a dynamic testing strategy is important to prevent outbreaks from a theoretical and empirical point of view. Hence, current political efforts to restrict testing capacities for unvaccinated people shall be reconsidered in the light of this analysis.

2.2.2 Consequences for Pandemic Development

Figure 3 illustrates the relationship between ICU patients (per million) and the Incidence in Italy. We observe that the relationship between both curves are completely different for the first versus the second and third waves. Even though the number of ICU patients peaks at the same level for all waves, the second and third waves are associated with peak Incidences higher by a factor of 4 to 6. The same effect can be observed in Denmark and France in Figures 7 and A in the Appendix.

As exhaustive test infrastructure has been set up between the first and the second wave, more tests were conducted (s. Table 1) which lead to higher Incidences for the same level of ICU admissions.

This effect shows that Incidence can be a misleading Statistic if not corrected for the testing capacity. While this particular scenario was quite predictable, it sheds light on the importance of correcting case numbers for testing, especially after many major test centres have been shut down in Germany [2].

2.3 Low ICU Capacities Outweigh Low Incidence

Even an unbiased statistic to measure the infection rates does not contain enough information to determine appropriate policies. A given infection rate must be weighted stronger for regions in which hospitals are close to their capacity limits than for regions with mostly vacant ICUs.

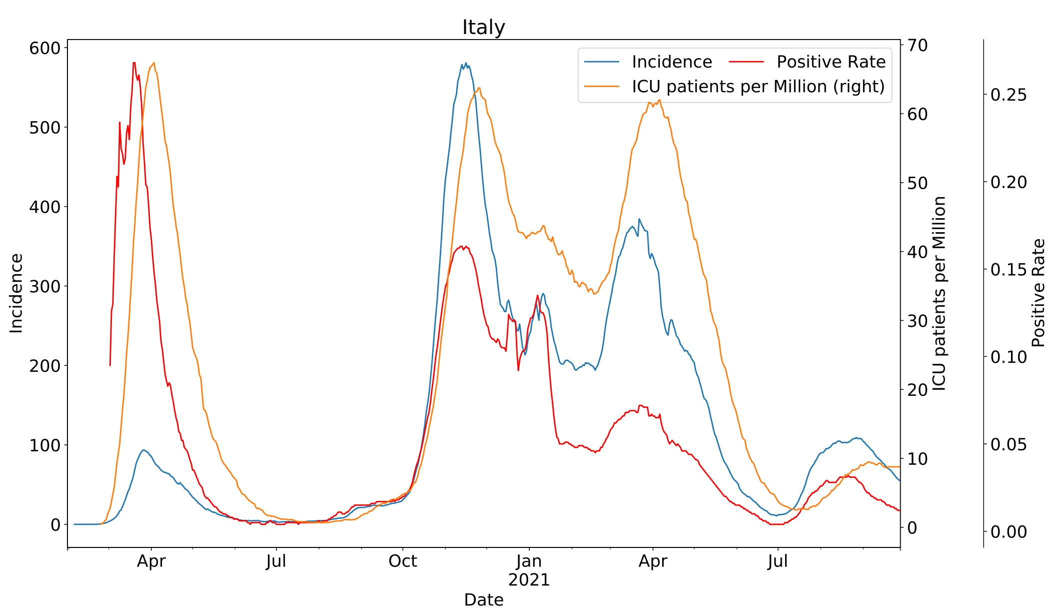

Figure 3: ICU Occupancy and Incidence in Italy

If the ICU-occupancy is ignored, scenarios similar to the third wave in Italy may emerge. In Figure 3 an Incidence of around 600 marks the peak of the second wave, the maximum Incidence during the third wave is below 400. However, the number of ICU patients per million peaks for both waves at an equal level of around 60.

The orange curve indicates that 50% of the ICU beds were still occupied at the beginning of March 2021, when the third wave started. Consequently the Incidence of 400 is associated with completely different grades of pandemic severity, when comparing the second and third wave. At the time of peak Incidence during the third wave ICU capacities were maxed out, while the exact same Incidence corresponds to only around 30% ICU occupation at the end of October 2020. The same effect can be observed in France, illustrated in Figure A in the Appendix.

Note that this discrepancy can not be explained by a decrease of testing intensity during the third wave. In fact, even more tests were conducted during the third wave than during the second wave. At the time of peak Incidence 6.1 tests were conducted per positive case during the second wave, whereas this statistic amounts to 14 for the third wave.

Even though this scenario was observed during a time with, generally speaking, high Incidence, it showcases that low Incidence shall not imply looser contact restrictions, if ICUs are mostly occupied. Thus, Incidence must be corrected for the current ICU occupancy.
While our whole analysis operates on the national level due to data availability, this effect really comes into play on regional level. Since hospital transfers are not feasible on a large scale, thresholds shall be determined in dependence of regional ICU capacities.

Finally, regions with low vaccination rates need to weigh high Incidence stronger than almost fully vaccinated regions, since 95% of all ICU Covid patients in Germany are not vaccinated [10] (September 2021). The following section sheds some light on vaccination effects.

2.4 Vaccination Disentangles Incidence from ICU Occupancy

Since vaccination rates have increased, we observe a drift in the relationship between Incidence and ICU occupancy.

Figure 3 reveals this disentanglement to a mild extent. The ICU curve follows the trend of the Incidence curve with a minor time lag up until the last local minimum at the beginning of July 2021. Afterwards we observe a larger than usual delay of the ICU curve. Additionally the slope of the ICU curve is visibly smaller than for the Incidence curve. Note that the latter has never been the case after the first wave: The slopes are almost identical throughout the second and third waves from a visual point of view.

Figure 4 emphasizes the disentanglement by showing Cumulative Incidence and Cumulative ICU Occupancy along time. The dotted vertical lines indicate Vaccination Progress: First Dose, 10%, 25%

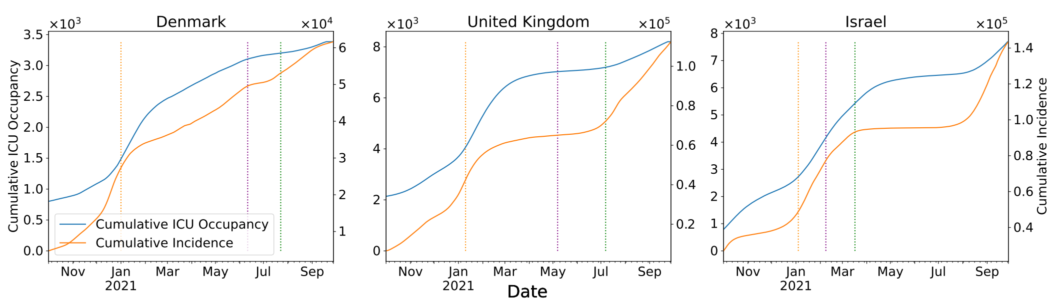

Figure 4: Effect of Vaccination on ICU Occupancy. Cumulative ICU Occupancy and Cumulative Incidence along time. Cumulation computed since the beginning of the pandemic. Dotted Lines indicate Vaccination Progress: First Dose, 25% and 50% fully vaccinated.

and 50% share of fully vaccinated population. Large slopes represent fast increase of Incidence (or ICU Occupancy), whereas constant pieces in a curve signify that no cases have been reported during that time period.

At first glance, we notice that Israel had the fastest vaccination progress. While all three countries started vaccinating in January, half of Israel's population was fully vaccinated in late March, whereas it took the United Kingdom (UK) and Denmark three to four months longer to reach that milestone.

The first panel illustrates the success of the vaccination campaign in Denmark. After vaccination has begun, the slope of the ICU curve (blue) decreases monotonically, while the slope of the Cumulative

Country	Israel				Italy			
Wave	1st	2nd	3rd	4th	1st	2nd	3rd	4th
Peak Incidence	70	715	980	1255	94	576	385	109
Peak Tests p. 1000	1.5	5.8	12.8	19	1	4.8	5.5	4.7
Peak Month	04/20	09/20	01/21	09/21	03/20	11/20	03/21	08/21

Table 1: Testing Capacities During Peak Incidence. Number of Tests is relative to 1000 inhabitants.

Incidence (orange) remains more or less constant. This implies that a constant Incidence is associated with less and less ICU admissions as the vaccination campaign progresses.

UK and Israel were exposed to the third wave when the vaccination campaign started. Both countries reported almost no new cases from March 2021 (end of March for Israel) ongoing for five months.

After new infections came about around July 2021 (August respectively), we observe different magnitudes of the vaccination effects. For UK: While the slope of the Cumulative Incidence curve increases in comparison to the end of 2020, the slope of the Cumulative ICU curve decreases (in comparison to the end of 2020). In contrast, Israel's plot exhibits almost equal slopes during that time and its third wave!

This observation reveals the decay of vaccine protection. While the vaccines currently continue to slow down ICU demand in the UK, the effect has vanished in Israel already. Large parts of the Israeli population was vaccinated earlier, suggesting that this phenomenon can be explained by the decline of vaccine effectiveness. Manufacturers of mRNA vaccines have disclosed data showing that the efficacy decreases substantially after six months [9].

Note that there have been no anomalies in testing strategy in either of the three countries for the investigated time frame. Thus there is no need to correct the Incidence for Positive Rate for the above considerations.

In conclusion, when adjusting the Incidence for vaccination effects, we need to model their impact along two dimensions. First, an increasing rate of fully vaccinated population is associated with lower demand for ICU beds. Second, higher demand for ICU beds is expected when the latest vaccine has been administered roughly half a year ago for a large groups of the population.

3 De-Biasing Incidence

The following subsection leverages the Positive Rate to adjust Incidence for the Testing Strategy Bias introduced in 2.2. By no means it is intended to resemble a predictive model but only aims to illustrate that the bias can be mitigated in a simple manner and with available data.
Correcting for the Vaccination and ICU Occupancy Biases is rather straight forward and not subject of this analysis. The second subsection addresses ethical and social conflicts which arise when we consider to alleviate the biases by means of a sophisticated Time Series Prediction Model.

3.1 Adjusting for Positive Rate

Incidence underestimates the pandemic severity, if it is observed in conjunction with disproportionately high Positive Rates. In such scenarios we increase the Incidence in an exponential manner, given that infections spread exponentially. We multiply the Incidence with the exponentially weighted Positive Rate. This correction is only applied when the standardized ratio of Positive Rate to Incidence is above a hard threshold $t = 2.5$. To this end we normalize both curves on the interval [0, 1] before computing the ratio.

$$\mathrm{PSM1}_t = \begin{cases} I_t(100r)^\alpha, & \text{if} \quad \frac{PR_t^{(norm)}}{I_t^{(norm)}} > t = 2.5 \\ I_t 5^\alpha, & \text{else} \end{cases},$$

where $r \in [0, 1]$ is the positive rate and $\alpha = 1.3$ the parameter defining the influence of the positive rate. 5^α only serves as a scaling factor, assuming 5% as the baseline Positive Rate level (cf. [4]). Notice that it is independent of the Positve Rate.

The result is depicted in Figure 5, which emphasizes its impact on the assessment of pandemic severity during the first wave. While the solid curves show ICU Occupancy, the blue Area fills the

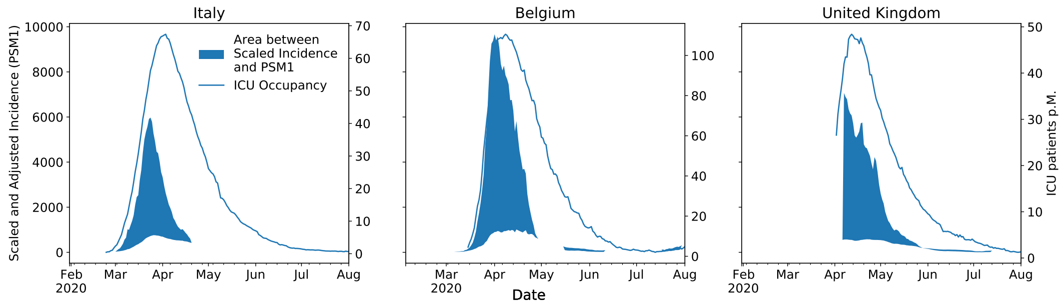

Figure 5: Correcting for Testing Bias: The blue area highlights the difference between Adjusted and regular Incidence (equally scaled). UK data missing until April.

space between the PSM1_t and the appropriately scaled Incidence (i.e. $I_t 5^{\alpha}$). Both metrics only differ during the time period where the area is visible.
In all three countries, PSM1 increases the Incidence for large periods of the first wave. While the Incidences (lower margins of the area) do not reveal the exponential nature of infections, PSM1 (upper margin) does. This demonstrates that accounting for the Positive Rate can capture the pandemic severity in a more appropriate way than raw Incidence.

3.2 Biases in the Context of Time Series Prediction

Building and evaluating a model to predict ICU occupancy on a statistically rigorous level lies beyond the scope of this work. The political implications of such an algorithm raise ethical questions which influence the model choice.

Most likely, a sophisticated probabilistic model with epidemiological priors, or a spatio-temporal neural network could achieve the highest predictive performance for regional ICU occupancy. However, the model's complexity – involving distributional assumptions, elements of randomness and a high number of variables – can not be communicated to the general public in a fully transparent manner.

The public's trust in political decisions is a key ingredient to successful pandemic management. Hence, prior to building a sophisticated predictive model, one needs to answer the societal question:

Which models can be communicated to the general public, such that laymen can trust the political decisions derived from the model?

4 Limitations and Conclusion

Even though the analyses hint at problems with the pandemic management it lacks a concrete solution to solve them. In practice, vaccination efficacy depends on more than the two highlighted variables. Vaccination Types in combination with virus variants have to be considered to investigate the effect exhaustively. The adjustment for Testing Strategies leverages the Incidence to Positive Rate ratio, which is based on normalized curves. While the correction was only demonstrated for the first wave, the normalization onto [0, 1] could not have been computed at that time. Thus, a completely different approach is required for predictive purposes.

While Incidence is a coarse real time indicator for the number of infections it is by no means optimally predictive for the primary variable of interest: The ICU Capacity in a specific region. Accounting for three major biases can increase its expressiveness substantially.
Adjusting for the Positive Rate can mitigate underestimation of pandemic severity that arises from insufficient testing. Attaching more weight to Incidence when current ICU capacities are low is necessary to prevent overloading when Incidence recovers from a wave but ICUs are still occupied. Although vaccinations relieve ICUs for some time, their effect must be modelled dynamically to account for the decay of efficacy after half a year.
The results suggest that it is dangerous to close test centres right now. Testing Data needs to be collected on a regional, not only the national level. Contact regulation thresholds shall be set according to local ICU capacities.

A Appendix

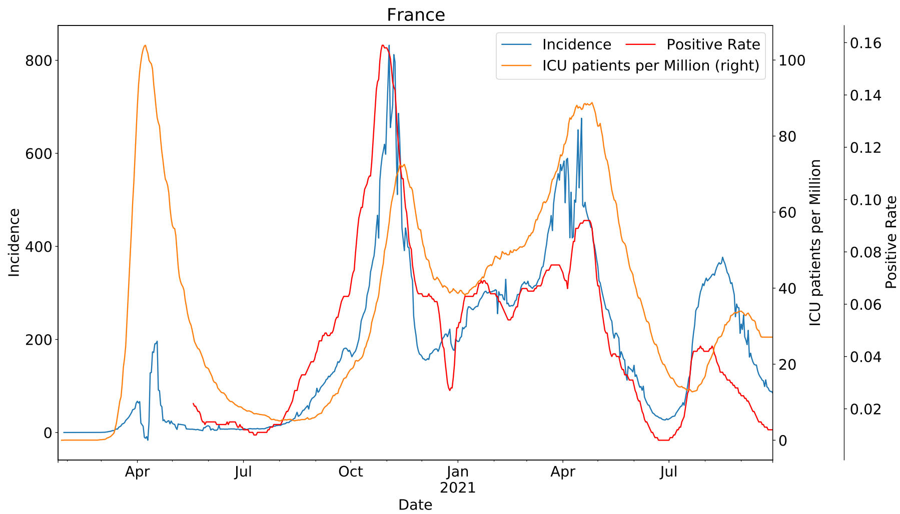

Figure 6: ICU Occupancy and Incidence in France

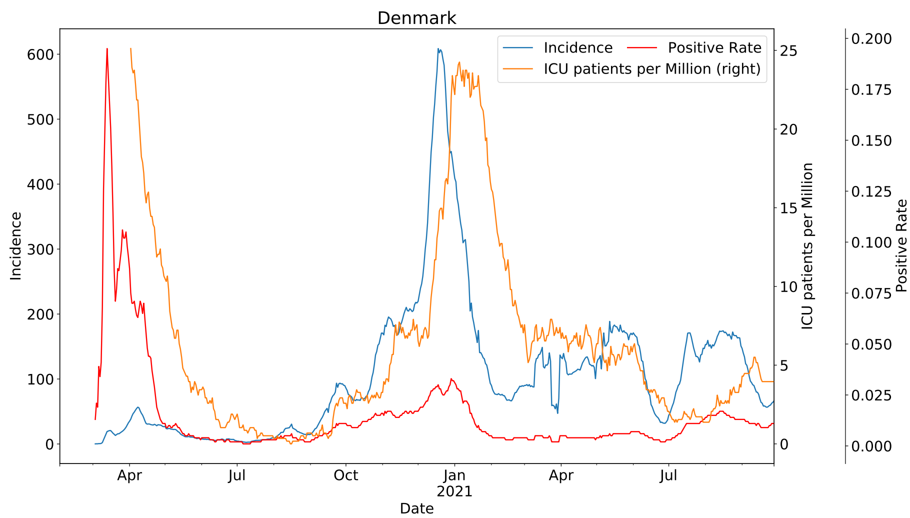

Figure 7: ICU Occupancy and Incidence in Denmark

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