The Effectiveness of Strategies to Contain SARS-CoV-2: Testing, Vaccinations, and NPIs *

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June 5, 2021

One-sentence summary

Among many measures, large-scale rapid testing has had the largest effect on reducing SARS-CoV-2 infections in Germany in 2021

Background:

Spread disease, initially NPIs, now testing and vaccines; seasonality unclear.

Objective: Provide a model that allows studying these things in conjunction, allowing for different virus strains.

Results: Along the transition to vaccination-induced herd immunity, testing is most effective, also thanks to family structures. Seasonality contributed its share.

Conclusions: Frequent rapid testing should remain part of strategies to contain CoViD-19.

JEL Classification: C63, I18
Keywords: Covid-19, agent based simulation model, public health measures

[Tobias 1]
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*Gabler, von Gaudecker and Röhrl are grateful for financial support by the German Research Foundation (DFG) through CRC-TR 224 (Projects C01, C01 and A02, respectively). Von Gaudecker is also grateful for support by the DFG through the German excellence strategy (Excellenzcluster ECONtribute – EXC 2126/1–390838866). Gabler is grateful for funding by IZA Institute of Labor Economics. We gratefully acknowledge support from the Google Cloud Covid-19 research credits program.

Since early 2020, the CoViD-19 pandemic has presented an enormous challenge to humanity on many dimensions. The development of highly effective vaccines holds the promise of containment in the medium term. However, most countries find themselves many months—and often years—away from reaching vaccination-induced herd immunity. In the meantime, it is of utmost importance to employ an effective mix of strategies for containing the virus. The most frequent initial response was a set of non-pharmaceutical interventions (NPIs) to reduce contacts between individuals. While this has allowed some countries to sustain equilibria with very low infection numbers, most have seen large ups and downs in their infection rates. Containment measures have become increasingly diverse and included testing, more nuanced NPIs, and contact tracing. Neither these policies' effect nor the influence of seasonal patterns or more infectious virus strains are well understood in quantitative terms. This paper develops a model incorporating all these factors. The framework allows to combine a wide variety of data in a timely fashion, making it useful to predict the effects of various interventions. We apply the model to Germany and show that rapid testing had the largest impact on the reduction in infections by XXX% during the A weeks between X April and Y May.. We conclude that rapid tests should play a large role...

[HM 1]
Cite some paper on herd immunity, maybe vaccine data

[HM 2]
Cite Priesemann paper or other

[HM 3]
insert some useful numbers

1 Introduction

The first wave of the Covid-19 pandemic prompted strict lockdowns and restrictions across the world. The reaction to second waves consisted of more targeted policy measures such as splitting school classes, closing restaurants and encouragement of home office. To combat the third and fourth waves, that were triggered by the spread of more infectious variants, governments relied on the same targeted measures and previously non-available tools such as large scale rapid testing and vaccinations.

While this multitude of policy measures has led to declining case numbers in most countries, it becomes harder and harder to evaluate the contribution each policy had on the overall outcome. Moreover, the longer the pandemic lasts, the more important it becomes to accurately model heterogeneities in contact behavior and a realistic network of recurrent contacts because some sub-populations might develop herd immunity even though the full population does not.

The workhorse model of epidemiology, the S(E)IR model as well as many recent extensions to it are not up to this task. We develop an agent-based simulation model that has been designed from the ground up to predict and quantify the effects of contact reducing policies, vaccinations and testing strategies in a constantly changing policy environment. It has the following features:

(1) At the core of the model, people meet people based on a matching algorithm. We distinguish various types of contacts. The contact types are households, leisure activities, schools, preschools, and nurseries and several types of contacts at the workplace. Contact types can be random or recurrent and vary in frequency and infectiousness.

(2) Policies can be implemented as shutting down contact types entirely or partially. The reduction of contacts can be random or systematic. For example, it is possible to implement split class schooling where only one half of each class attends and the attending half switches on a weekly bases. The extent to which contacts are reduced can be calibrated from observed data or estimated inside the model.

(3) Infection probabilities vary across contact types and reflect properties of the contact like the location (indoor/outdoor) and the kind of interaction (duration, physical contact). The probabilities are independent from the number of contacts and, thus, policy-invariant.

(4) We distinguish detected and undetected cases. The share of detected cases varies over time and across age groups. Moreover, it can be influenced by rapid testing policies.

(5) High quality Python code for the model is freely available on Github, well documented and very flexible[1].

1. The code can be found at https://github.com/covid-19-impact-lab/sid and the documentation with tutorials and background information at https://sid-dev.readthedocs.io/.

The model achieves a good fit on German data of infection and fatality rates, even though most parameters are calibrated from the literature and observable datasets and only a few parameters are estimated inside the model. It accurately predicts the rise of the B117 mutation in spring 2020. It can also explain the surprising decline of case numbers at the end of April, without making ad hoc assumptions on behavioral changes at the time.

The model has previously been applied to predict the effect of schooling policies, contact tracing policies over the Christmas holidays and the effect of work from home (Dorn, Gabler, Gaudecker, Peichl, Raabe, et al. (2020), Gabler, Raabe, Röhrl, and Gaudecker (2020), and Gabler, Raabe, Röhrl, and Gaudecker (2021)).

Summary of the main results

The remainder is structured as follows: In Section 2, we give a short overview of epidemiological models. Section 3 summarizes the policy environments and dynamic of the Covid-19 pandemic in Europe, with a special focus on Germany. We continue with a general description of our modelling framework as well as a specialization to the German context in section **??**. Section **??** describes our empirical datasets, sources of calibrated parameters and estimation procedure. desribe result section. We conclude in section **??**.

2 Literature Review

We build on two strands of literature: Recent extensions of the epidemiological SEIR model and agent-based simulation models.

The traditional SEIR model is not fine-grained enough to model nuanced policies. This has motivated a large number of researchers to extend the standard model to allow for more heterogeneity and flexibility. Examples are Grimm, Mengel, and Schmidt (2020), Donsimoni, Glawion, Plachter, and Wälde (2020) and Acemoglu, Chernozhukov, Werning, and Whinston (2020) who develop multi group SEIR models to analyze the effects of targeted lockdowns and Berger, Herkenhoff, and Mongey (2020) who extend the SEIR model to analyze testing and conditional quarantines. For a more comprehensive review see Avery, Bossert, Clark, Ellison, and Ellison (2020). Others have used the results of a standard SEIR model as input for economic models that estimate the cost of policies (e.g. Dorn, Khailaie, Stöckli, Binder, Lange, et al. (2020)).

While the popularity of the SEIR model is mainly due to its simplicity, the extensions are quite complex. It is unlikely that there will be a SEIR model that combines all proposed extensions. Moreover, the extensions do not address other key issues: The main parameter of the SEIR model, the basic reproduction number (R_0), is not policy-invariant. It is a composite of the number of contacts each person has and the infection probability of the contacts. In fact, policy simulations are done by setting R_0 to a different value but it is hard to translate a real policy into the value of R_0 it will induce. In other words, SEIR models are not suited for evaluating the effect of policies which have never been experienced before.

Another commonly used model class in epidemiology are agent-based simulation models. In these models individuals are simulated as moving particles. Infections take place when two particles come closer than a certain contact radius (e.g. Silva, Batista, Lima, Alves, Guimarães, et al. (2020) and Cuevas (2020)). While the simulation approach makes it easy to incorporate heterogeneity in disease progression, it is hard to incorporate heterogeneity in meeting patterns. Moreover, policies are modeled as changes in the contact radius or momentum equation of the particles. The translation from real policies to corresponding model parameters is a hard task.

Hinch, Probert, Nurtay, Kendall, Wymatt, et al. (2020) is a recent extension of the prototypical agent-based simulation model that replaces moving particles by contact networks for households, work and random contacts. This model is similar in spirit to ours but focuses on contact tracing rather than social distancing policies.

The above assessment of epidemiological models is not meant as a critique. We are aware that these models were not designed to predict the effect of fine-grained social distancing policies in real time and are very well suited to their purpose. We invite epidemiologists to provide feedback and collaborate to improve our model.

3 Background: The Situation in Germany

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