Mathematical modelling of the COVID-19 epidemic across England, Scotland, Wales and Northern Ireland using an agent-based model

Introduction

Since early 2020 the SARS-CoV-2 epidemic in England has continued to grow, particularly driven by the emergence of different viral variants. Mathematical modelling has played an important role in modelling the transmission of these variants and in evaluating the impact of different non-pharmaceutical interventions (NPIs such as lockdown, circuit breakers or Test-Trace-Isolate (TTI) strategies) and pharmaceutical interventions (PIs eg vaccination or antivirals). Since the onset of the pandemic, the Covasim model [1] has been used to model the UK-wide (in 2020) and the English (throughout 2021 and 2022) epidemic. Covasim is an agent-based model that combines within-host framework describing the accumulation and waning of infection or vaccination derived immunity with a between-hosts framework that captures the transmission of COVID-19 within specific settings such as schools, workplaces, household and the wider community, setting rules of how they are interlinked within the wider network.

Published Covasim work on the UK (in 2020) and the English (throughout 2021 and 2022) epidemic has evaluated the impact of different TTI strategies when schools reopened after the first national lockdown [2], explored the impact of wearing face coverings in schools [3], simulated different lockdown lifting strategies and explored the impact of vaccination during the alpha epidemic wave in early 2021 [4-5]. Additionally, the model for the English epidemic and a separate version of it tracking the Scottish COVID-19 epidemic have been used within SPI-M and as part of the UK Health Security Agency for epidemic nowcasting [6].

Project

This project will expand the existing portfolio of Covasim work in the UK in a number of directions.

a. Separate models calibrated to the COVID-19 epidemic in Wales and Northern Ireland will be developed and fitted to publicly available data over the period January 2020-December 2022. These models will incorporate different NPIs and PIs across different settings, and explore the impact of such strategies retrospectively.

b. The existing Covasim model for England will be adapted to incorporate theoretical variants with different transmissibility and immune escape characteristics from the Autumn 2022. The adapted model will be used to evaluate the possible impact or prospective interventions needed to curb infections, hospitalisations and deaths from the hypothetical variants.

c. The modelling analysis will include both simple parameter runs as well as large scale parameter sweeps across a number of parameters during sensitivity analysis.

d. A number of possible futures will be explored under different assumptions and caveats and across different settings.

e. Two different calibration techniques (A hyperparameter search using Optuna package [7] and a Machine Learning Algorithm combined with a rejection Approximate Bayesian Computation [8]) will be tested against a subset of the models and their difference quantified.

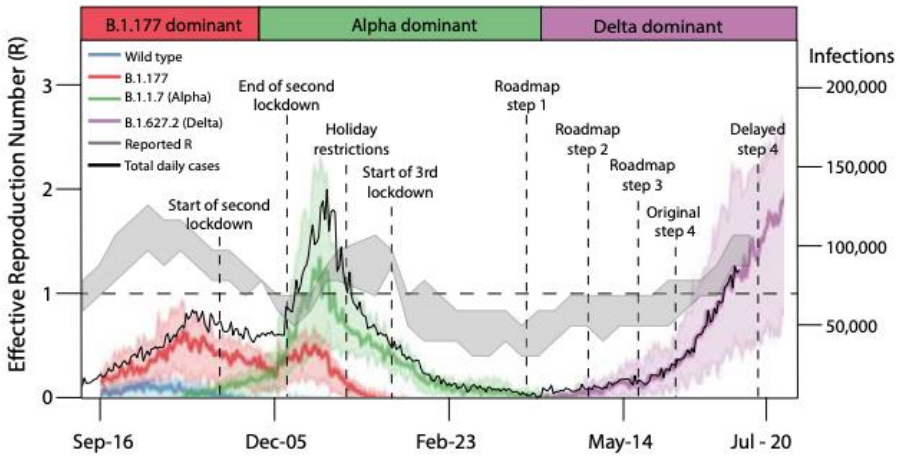

Figure 1: Covasim model-generated [5] daily infections by different SARS-CoV-2 variant type (blue, red, green and purple lines), together with data on the total number of daily cases (black line; all on the right y-axis)) and the reported Effective Reproduction number R value (grey band and on the left y-axis)), in England between September 2021 and June 2021. Bold coloured lines show the median over 100 simulations, and the shaded intervals around these show the 90% confidence interval across the simulations.

Prerequisites

An interest in learning to write and read, understand and interpret numerical code for statistical analysis in Python. Support will be given and existing codes can be shared which can be adapted, extended and expanded for the purposes of this project.

Good understating of the probability theory taught within the A8 module and of the statistical methods taught within the A9 module.

Interest in epidemiological modelling and in interdisciplinary translational work with ability to communicate analysis and results with epidemiologists, computer scientists, mathematicians and statisticians.

Reading

[1] Kerr CC, Stuart RM, Mistry D, et al.Covasim: An agent-based model of COVID-19 dynamics and interventions. PLoS Comput Biol. 2021 Jul 26;17(7):e1009149. doi: 10.1371/journal.pcbi.1009149.

[2] Panovska-Griffiths J, Kerr CC, Stuart RM, et al. Determining the optimal strategy for reopening schools, the impact of test and trace interventions, and the risk of occurrence of a second COVID-19 epidemic wave in the UK: a modelling study. Lancet Child Adolesc Health. 2020 Nov;4(11):817-827. doi: 10.1016/S2352-4642(20)30250-9. Epub 2020 Aug 3.

[3] Panovska-Griffiths J, Kerr CC, Waites W, et al. Modelling the potential impact of mask use in schools and society on COVID-19 control in the UK. Sci Rep. 2021 Apr 22;11(1):8747.

[4] Panovska-Griffiths J, Stuart RM, Kerr CC, et al.Modelling the impact of reopening schools in the UK in early 2021 in the presence of the alpha variant and with roll-out of vaccination against SARS-CoV-2. J Math Anal Appl. 2022 Oct 15;514(2):126050. doi: 10.1016/j.jmaa.2022.126050.

[5] Panovska-Griffiths J, Hinch, R, Swallow B, et al. Statistical and agent-based modelling of the transmissibility of different SARS-CoV-2 variants in England and impact of different interventions. Phil Trans Roy Soc (in press). 2022. doi:10.1098/rsta.2021.0315.

[6] Reproduction number (R) and growth rate: methodology, UK Health Security Agency (2021) https://www.gov.uk/government/publications/reproduction-number-r-and-growth-rate-methodology/reproduction-number-r-and-growth-rate-methodology

[7] Optuna calibration package https://optuna.org

[8] Minter A, Retkute R. Approximate Bayesian Computation for infectious diseases modelling. Epidemics. 2019. Vol 29, doi: 10.1016/j.epidem.2019.100368.