Technical Advisory Group

A Calibrated Local Authority Level COVID-19 Epidemic Policy Model for Wales

Prepared 20th July 2020 by Modelling Subgroup[1]

Summary

We have prepared a stochastic age-structured SEIR epidemic model for exploring policy scenarios in Wales, with a particular focus on the impact of changes in contact structures at schools, work, home, community and shielded environments. The model uses the explicit demographics for Wales at the local authority level. The model is installed on the Supercomputing Wales high performance computing cluster, allowing rapid exploration of a great number of parameter combinations. In a calibration exercise we estimated the initial R_0 in Wales to be approximately 2.5, and identified the impact of reduced contacts due to social distancing over lockdown. Under these scenarios, the model indicates that if lockdown measures were delayed by only 5 more days, an expected 28% more deaths may have been expected. In line with other recent modelling exercises at the UK level, earlier lockdowns would have likely prevented a considerable number of deaths and reduced the duration of the main epidemic. In the scenarios explored here, a lockdown only 5 days earlier would have led to 24% fewer deaths. Following this calibration exercise, the model can be used to forecast possible future trajectories of the epidemic, starting with the current likely exposure history of Wales at the local authority level. Forecasts can be used to measure expected age-specific asymptomatic infections, symptomatic infections, hospitalisations, intensive care bed occupancy, and deaths.

The model

At the UK level, SAGE and the modelling group SPI-M have provided a number of very detailed simulation models for COVID-19 analysis and forecasting. We explored a range of these models, available on the code open access repository GitHub, for use in analysing the outbreak in Wales. The analysis provided here is based on the dynamic transmission model covid-uk, prepared and published by Davies et al at the Centre for Mathematical Modelling of Infectious Disease (CMMID, London School of Hygiene and Tropical Medicine). Full details of the model are available in Davies et al[2], and https://github.com/cmmid/covid-uk. Briefly, the covid-uk model structure is:

- Stochastic, tracking up to 66.4 million people at the UK level over time steps of 6 hours, hence the output is probabilistic and a distribution of outcomes can be obtained from a fixed set of parameters.
- Age-structured into 16 age bands, with demographics provided at the local authority level.

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[2] N Davies et al (2020). Effects of non-pharmaceutical interventions on COVID-19 cases, deaths, and demand for hospital services in the UK: a modelling study. *The Lancet Public Health* 5 (7) E375-E385. DOI:https://doi.org/10.1016/S2468-2667(20)30133-X

- There are 6 Disease states: Susceptible (S), and after successful transmission Exposed (E) but not infectious. After a latent period approximately 50% of infectious individuals are asymptomatic (I_s), while the rest enter a pre-clinical, but infectious state (I_p) followed by a clinical symptomatic infectious state (I_c) followed by isolation and recovery (R). The waiting times in each state are gamma distributed[2].
- Age-specific hospitalisation rates, fatality rates, and duration of hospital stay, estimated from the early stages of the pandemic are used to monitor the impact of the epidemic and health service capacity[2].
- A detailed description of the transmission between individuals based on measured social mixing patterns provided by the POLYMOD study[3]. Contact matrices are provided for home, school, work and community, all stratified by age band.
- The force of infection at time *t* for an individual is then given by the product of the susceptibility to infection upon contact and the number of contacts per day (all age specific).
- Scenarios are explored by scheduling changes to the number of contacts expected in each age group, and how this varies over time, for example when schools open/close, when lockdown measures dramatically decrease contacts, and when relaxation gradually increases the contact rate.

Following modifications to allow for flexible initial conditions and flexible scheduling of combinations of interventions over long time periods, the version of the model we are now using is available on our code repository (https://github.com/sa2c/covid-uk).

Data

The model was fitted to daily incidence of death, which is assumed to be the most consistent and reliable indicator of the overall transmission dynamics. Data were provided by PHW and NHS Wales Informatics Service. The epidemic curves for Wales, and by Local Authority are given in Figure 1 and 2.

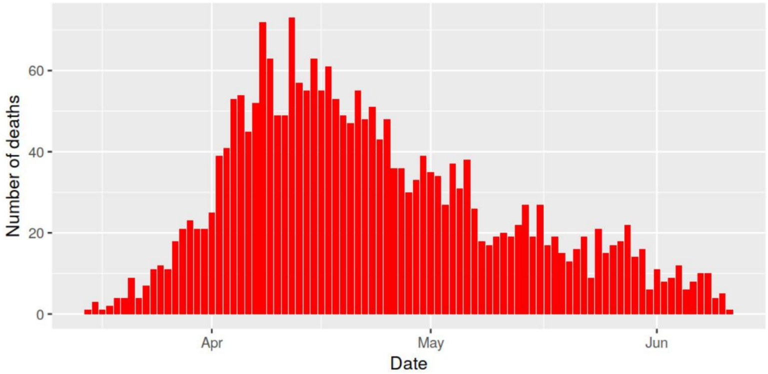

Figure 1. Number of deaths per day. All Wales counts.

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[3] Mossong et al (2008). Social contacts and mixing patterns relevant to the spread of infectious diseases. *PLoS Medicine* 5 e74.

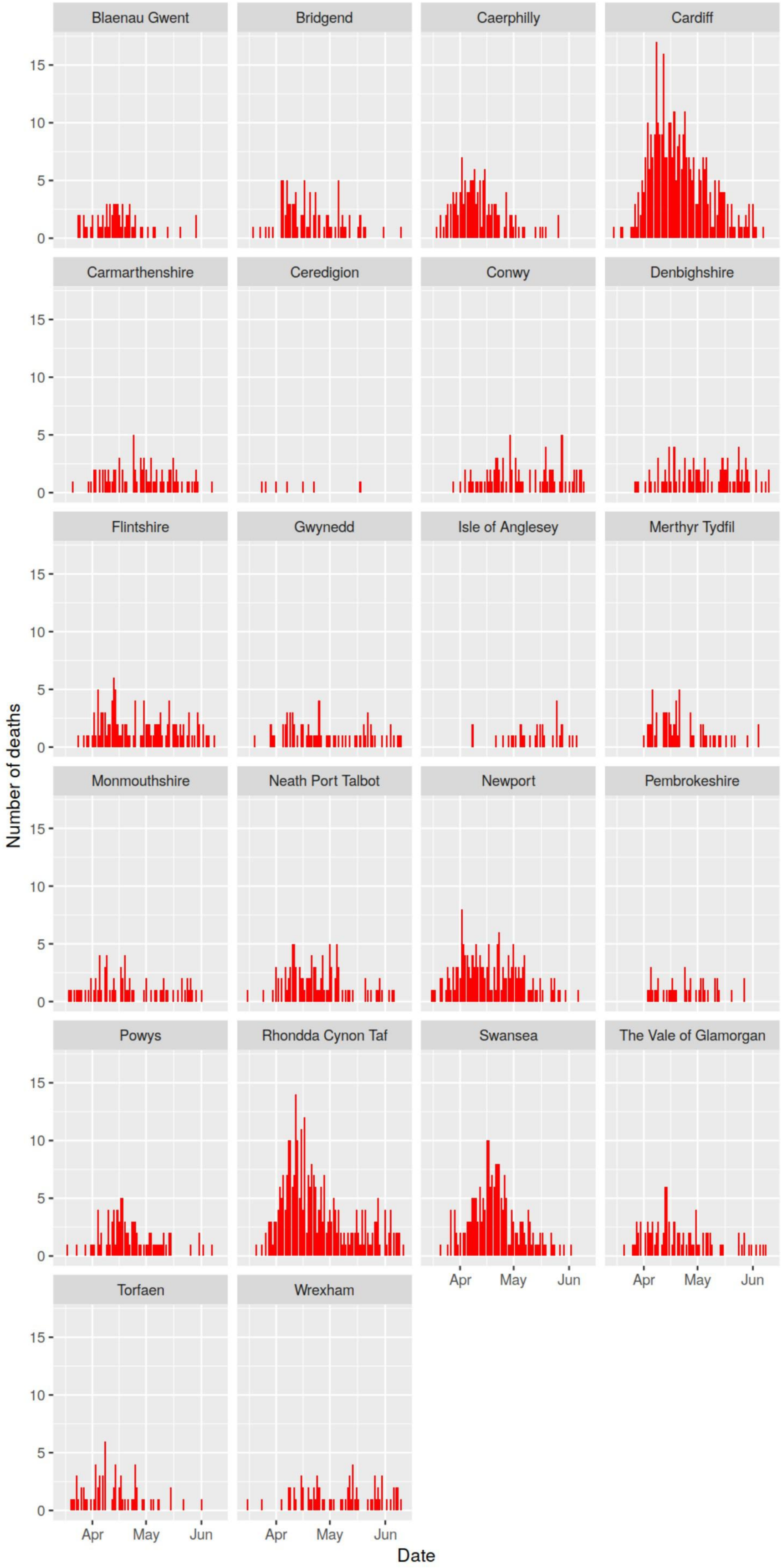

Figure 2. Number of deaths per day. Local Authority breakdown.

Calibration of the model to the Wales outbreak

Initial introductions to Wales at the start of the epidemic and R_0

There are a number of challenges to the estimation of parameters specific to the Wales outbreak. One in particular concerns the correlation between the number of introductions of the virus to Wales (the initial conditions or 'seeding') and the initial (basic) reproduction number, R_0. In our experiments we used an independent estimate of the intensity of seeding in Wales provided by COG genotyping studies[4]. This estimate (Figure 3) combines the relative intensity distribution and timing of all introductions to the UK (concentrated in late March) with the results of Wales case sequencing which quantify the number of independent transmission introductions. We use the latter as a scaling factor for the intensity.

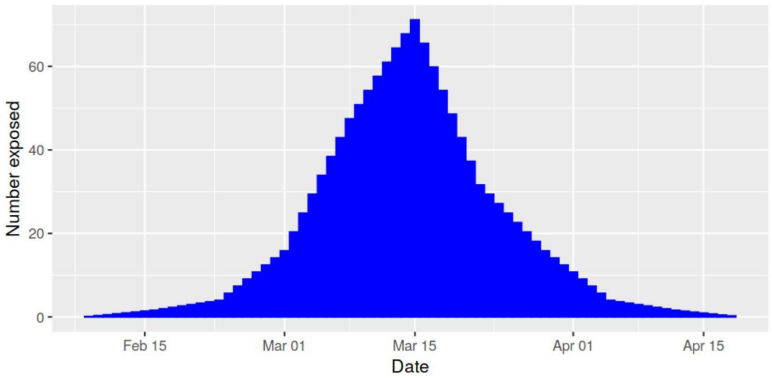

Figure 3. Estimate of initial introduction intensity in Wales. COG UK estimates of the intensity distribution can be scaled by a parameter representing the total number of transmission lineages identified in the Wales case sequencing studies.

Given a range of plausible initial conditions, we estimated the initial (basic) reproduction number R_0. We chose the R_0 value that minimised the χ^2 statistic measuring the difference between the observed daily death count and that simulated by the model. We note that (for a given initial seeding) the estimate was generally quite precise, and independent of assumed lockdown parameters. The likely reason for this was the use of death statistics, which represent transmission events that occurred a considerable time before lockdown interventions. In the scenario shown in figure 4, we estimate $R_0 = 2.5$, a value generally consistent with UK estimates.

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[4] Dr Tom Connor, pers comm; COVID-19 Genomics UK Consortium (https://www.cogconsortium.uk/); Pybus et al (2020) Preliminary analysis of SARS-CoV-2 importation & establishment of UK transmission lineages. Report #8. https://www.cogconsortium.uk/wp-content/uploads/2020/06/11th-June-2020-Report-COVID-19-Genomics-UK-COG-UK-Consortium.pdf

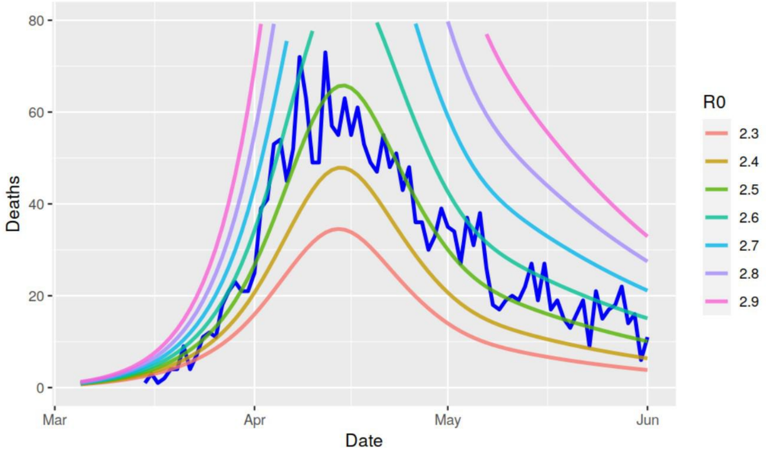

Figure 4. Estimate of R_0. Data shown in blue line. Note lockdown parameters (figures 5 and 6) are also included here to illustrate the full model calibration.

Estimate of Lockdown Parameters

Given the initial seeding and R_0, we estimated the effects of lockdown by exploring all combinations of 5 parameters. We assumed that contact rates declined prior to full lockdown due to altered population behaviour following awareness of the pandemic (*pre-lockdown*), and this occurred at a number of days prior to March 23rd (*pre-lock down delay*). We then assumed contacts were reduced by a l*ockdown* factor on March 23rd. Finally we assumed a return of some mobility and increased contacts by a *post-lockdown* factor, occurring at a *post-lockdown delay*. A typical fit of the model, representing a likely calibration for Wales is given in Figure 5. Not surprisingly, the data can be equally well described by a range of lockdown contact parameters. The parallel plot shows the range of parameter values consistent with the epidemic curve in Wales.

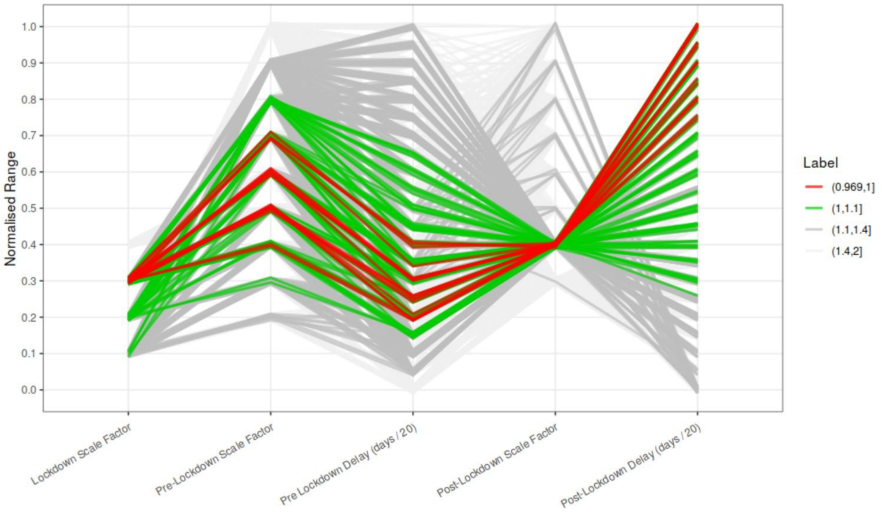

Figure 5. Parallel plot showing ranges of plausible lockdown parameters for Wales. Best fitting parameters shown in red.

In Figure 6 we illustrate the correlation between parameter values. The parallel plot is split into 3 panels, for a range of most plausible *lockdown* factors. The lines represent useful sets of baseline scenarios that can be used as starting points to model future policy changes.

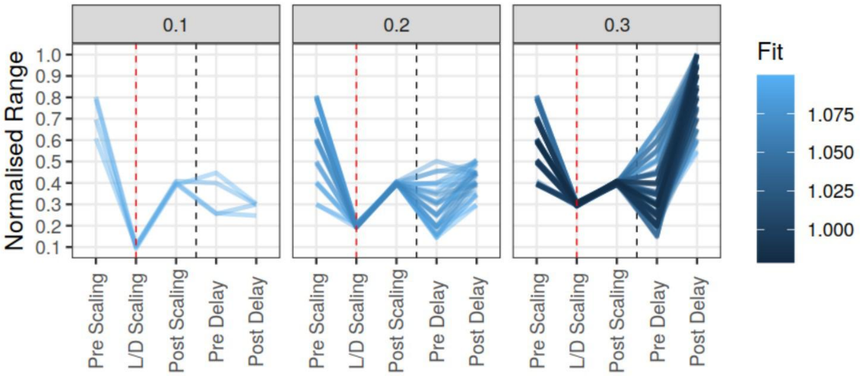

Figure 6. Sets of combinations of lockdown parameters that can be used as plausible baselines for future policy modelling. Best fitting parameters in deep blue.

Other model output can be illustrated in Figure 7, which shows the 6 compartments of the model using the 100 best fitting parameter sets. Note that the R compartment can be used to estimate total population exposure. In Figure 8, the simulations are broken down by age-group, which serves to highlight the highly skewed age distribution in the comparison of cases, in comparison to hospitalisation and death.

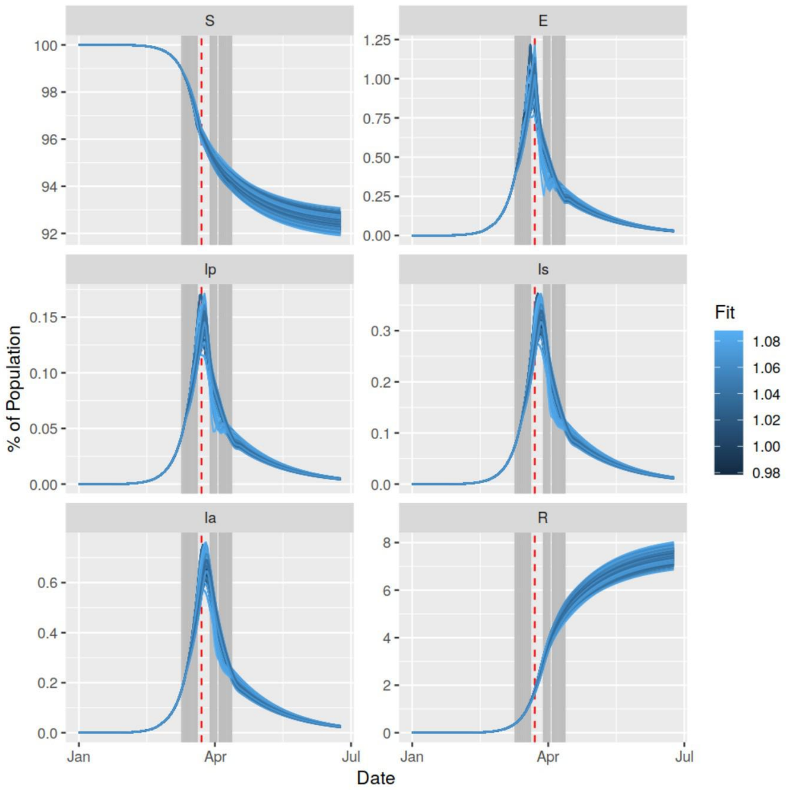

Figure 7. Detailed trajectories of 100 best fitting model simulations in the 6 model compartments

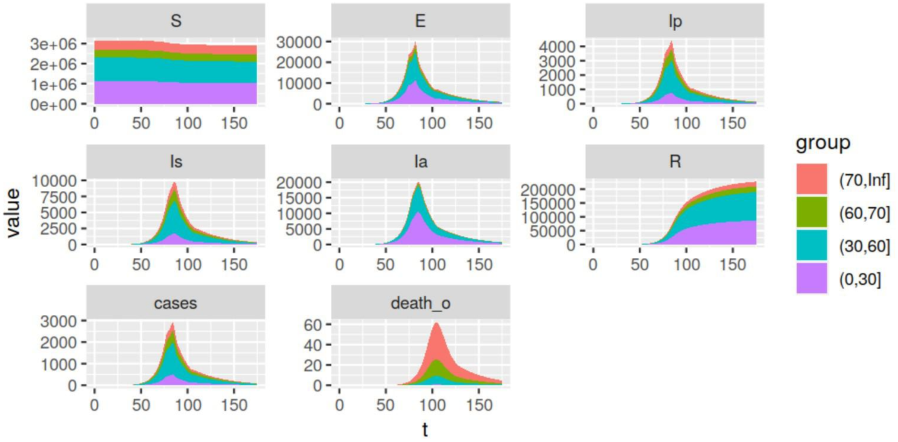

Figure 8. Age-specific trajectories of 100 best fitting model simulations in the 6 model compartments plus symptomatic cases and deaths.

Modelling the effect of lockdown timing

Figure 9 shows the effect of different timings of lockdown parameters on the potential course of the epidemic in Wales. We consider the shift of full lockdown combined with pre-lockdown behaviours in time, using parameters sampled from the fitted model. Under the scenario of no mitigation measures at all, the epidemic would be expected to have reached a very high peak in mid May. If only pre-lockdown reduction levels of contact were maintained (no full lockdown) a peak of over 250 deaths per day may have been expected near the beginning of June. Under scenarios of full lockdown, we investigated the sensitivity of total deaths to the timing of lockdown. If lockdown had been delayed by only 5 days, the scenarios here suggest an additional 28% of deaths would have occurred. If lockdown had been introduced only 5 days earlier than March 23rd an expected 24% of deaths may have been prevented. This sensitivity reflects the high growth rate of cases at this point in the epidemic.

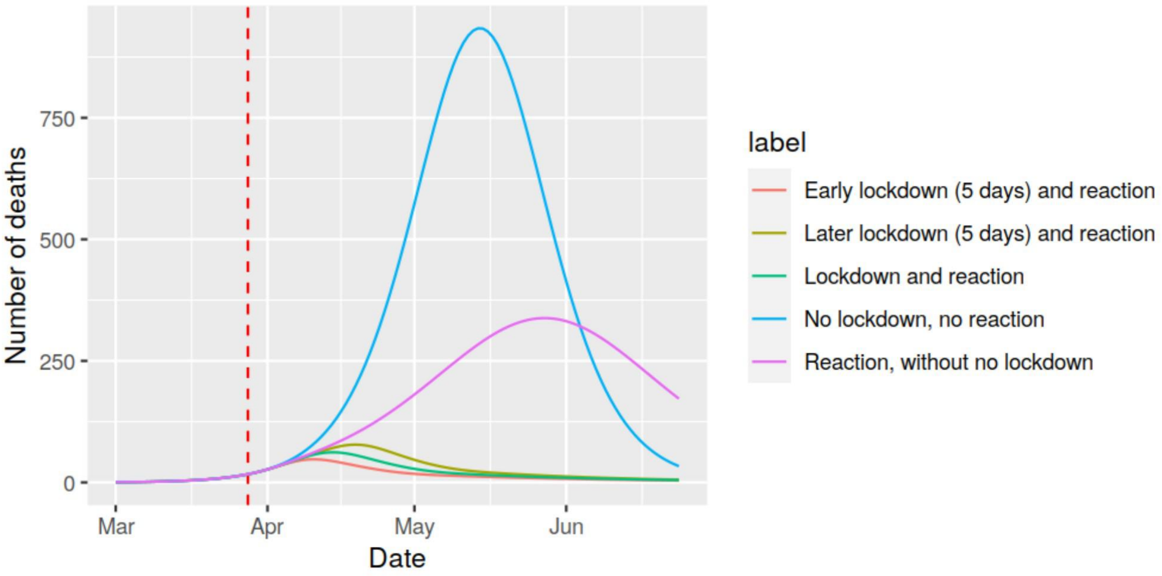

Figure 9. Estimated impact of lockdown timings on the epidemic in Wales. No epidemic mitigation at all (blue), No lockdown but initial sustained *pre-lockdown* social distancing (magenta), delayed lockdown (5 days) (olive green), calibrated to observed Wales outbreak (green), 5 days earlier lockdown (red).