COVID-19 Actuarial Modelling of the Pandemic

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► Insight Report

30 September 2020

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1. Multi-state actuarial model

NMG has built a multi-state actuarial model to forecast COVID-19 cases in a population and applied this model to the South African and other populations. The model can be calibrated to the latest reported South Africa experience to better understand how changes in the reported experience might impact on the longer-term outlook for the pandemic.

1.1 Workings of the model

The NMG model has adopted terminology that is commonly used for modelling infectious diseases. The 'susceptible' population are those lives who are at risk of being infected. For COVID-19, the entire South African population is susceptible. Lives in the 'susceptible' population get infected by coming into contact with infectious lives. Lives so infected are allocated to the 'exposed' population while they are in the incubation stage of the disease and therefore not infectious themselves. The lives move out of the 'exposed' population to one of three infectious states after the incubation period. The three infectious states are ‘symptomatic unreported’ (SU), ‘symptomatic reported’ (SR) and ‘asymptomatic unreported’ (AU). From the infectious states, the lives either recover or die.

The lives needing hospitalisation and fatalities from the disease can be estimated from the lives allocated to the symptomatic infectious states and the recovered/died state.

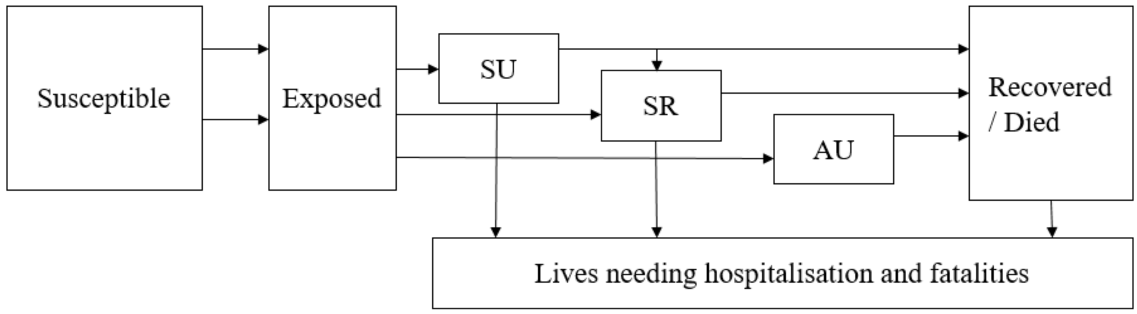

Figure 1 Workings of the model

For each day of the disease progression, the model uses parameters to determine the likelihood of lives remaining in their current state or progressing to another state.

1.2 Model parameters

The first set of model parameters determines the progression of the disease from 'exposed' to the three infectious states as follows:

- An incubation period that determines the length of time that a life remains in the 'exposed' state before moving to one of the three infectious states;
- An infectious period that determines how long a life remains in one of the three infectious states before moving to the 'recovered/died' state; and
- A fraction that determines the proportion of lives in the infectious states that are asymptomatic.

Lives move from the 'susceptible' state to the 'exposed' state when they come into contact with a life in one of the three infectious states. The rate at which infectious lives infect those in the 'susceptible' state is determined by three factors

- A transmission rate parameter that determines the number of lives that one infectious life will infect each day;
- A relative reduction parameter applied to the transmission rate parameter for infectious lives that are asymptomatic; and
- A 'herd immunity' reduction factor calculated as the ratio of the lives in the 'susceptible' state to the lives in the overall population. This factor is very close to 1.0 at the start of the pandemic but reduces as the numbers in the recovered state increase.

1.3 Assumptions for hospitalisations and fatalities

Lives requiring hospitalisation and fatalities can be derived from the lives allocated by the model to the two asymptomatic infectious states based on a number of assumptions:

- An Infection Fatality Ratio that is used to determine the number of deaths;
- A rate of hospitalisation that is used to determine the number of potential hospital admissions;
- An average stay in hospital that is used to determine the number of potential bed days;
- An average duration from onset of the disease to hospital admission; and
- An average duration from onset of the disease to death.

2. Setting the model parameters

The NMG model parameters were initially derived from a mathematical model used to analyse the reported infections in China over the period from 10 January 2020 to 8 February 2020. Some of the model parameters have since been updated to reflect more recent information from studies on the disease progression and severity in the United Kingdom and New York.

2.1 Variable model parameters

Certain model parameters and the seed values are adjusted to fit the NMG model to the experience of the disease progression in South Africa. These variable model parameters and seed values are as follows:

- The lives allocated to the symptomatic reported and the symptomatic unreported states;
- The transmission rate parameter; and
- The Infection Fatality Ratio that is adjusted for the age distribution of the deaths due to COVID-19 in South Africa.

The adjustment to the Infection Fatality Ratio (IFR) was made using the deaths reported to 8 June 2020. This gives an average IFR that ranges from 0.468% for Gauteng to 0.743% for Eastern Cape. An adjustment has been made to the assumed IFR’s to reflect an improvement of 33% to the ICU survival rates over the 30 days to 28 July 2020.

2.2 Fixed model parameters

The model parameters that are fixed in the NMG model based on international studies on the disease progression and severity are as follows:

- An incubation period of 5 days;
- An infectious period of 12 days;
- A fraction of 0.31 that determines the proportion of lives in the infectious states that are asymptomatic;
- A relative reduction parameter of 0.55 that is applied to the transmission rate parameter for infectious lives that are asymptomatic;
- A rate of hospitalisation of 5 times the deaths forecast using the Infection Fatality Ratio;
- An average stay in hospital of 7 days;
- An average duration from onset of the disease to hospital admission of 15 days; and
- An average duration from onset of the disease to death of 12 days.

The parameters for the fraction of infectious lives that are asymptomatic and the relative reduction parameter for the asymptomatic lives have been retained from the China study. There is little new evidence available that would support a change to these parameters.

The onset-to-hospital-admission parameter has been adjusted following a comparison of the reported hospitalisations and deaths for the Western Cape.

2.3 Viral propagation

The model assumes that the virus will move through a population where all individuals are equally susceptible to infection. In practice the virus will be constrained in its movements by the social contact networks that exist in the population.

The virus will infect the highly connected individuals first, and then the viral propagation will slow down when less connected individuals are left in the susceptible population.

This slowing down of the viral propagation has been built into the NMG model so as not to overstate the numbers that are forecast to eventually become infected. A parameter (% population infected parameter) must be entered that represents the percentage of the population that will have been infected when the virus stops spreading in the population.

The model transmission rate parameter will be reduced in stages until this parameter is attained to reflect this slowing down of the viral propagation.

A default '% population infected' parameter has been used in the NMG model of 25% for the Free State, Gauteng and the Western Cape and 20% for the other provinces. The default parameters for the provinces that have yet to reach a peak in infections will be adjusted as soon as the pattern of infections becomes clearer.

3. Model fit to the South African experience

The NMG model is fit (or calibrated) to the confirmed cases and deaths reported for each of the nine provinces of South Africa. The reported COVID-19 deaths are adjusted for underreporting using the Medical Research Council data on all cause natural deaths as a guide. The model fit is adjusted each week using the latest available statistics.

3.1 Calibration for the Western Cape

The COVID-19 deaths in the Western Cape are compared against three scenarios for the '% population infected' parameter in the graph below. The default parameter used in the model is that 25% of the population in this province will be infected in the first wave of COVID-19 infections.

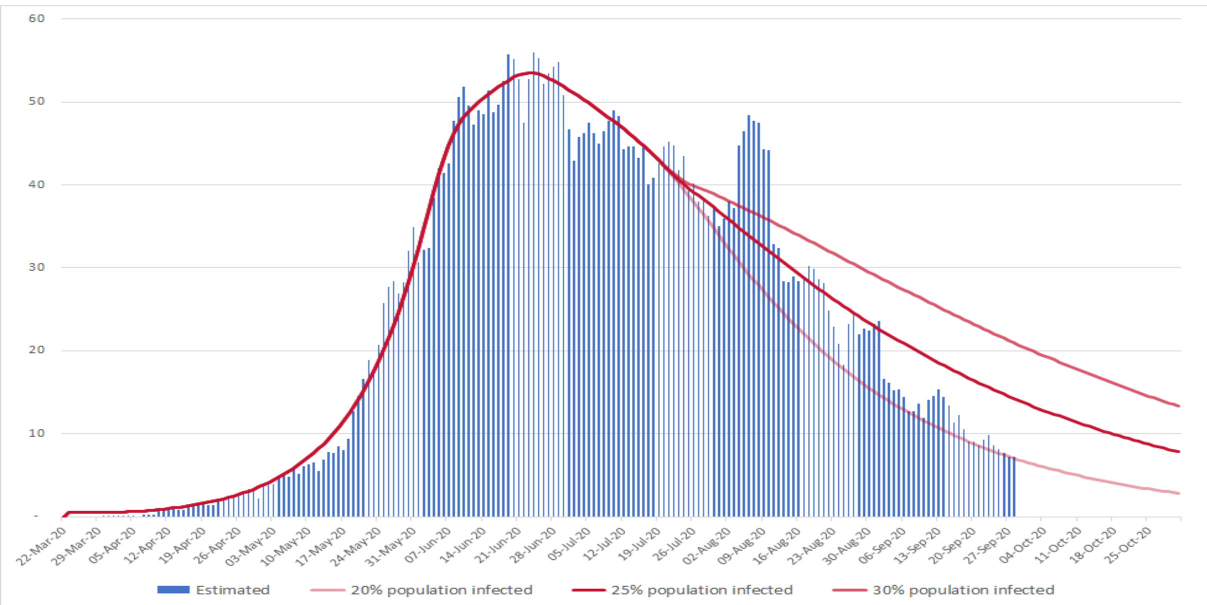

Figure 2 Forecast daily COVID-19 deaths (7-day moving average) – Western Cape

The daily reported COVID-19 deaths in the Western Cape have been increased by 10% to allow for unreported deaths due to COVID-19.

3.2 Calibration for Gauteng

The reported deaths in Gauteng are compared against three scenarios for the '% population infected' parameter in the graph below. The default parameter used in the model is that 25% of the population in this province will be infected in the first wave of COVID-19 infections.

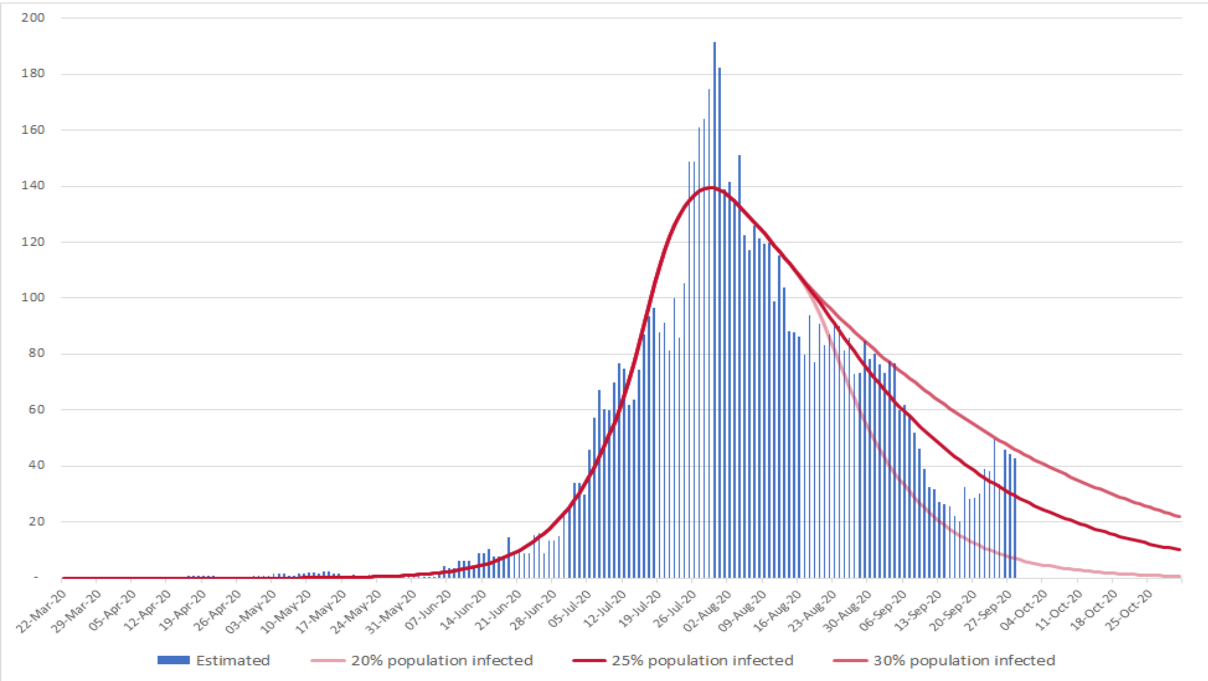

Figure 3 Forecast daily COVID-19 deaths (7-day moving average) – Gauteng

The daily reported COVID-19 deaths in Gauteng have been increased by 80% to allow for unreported deaths due to COVID-19. This is aligned with the data reported by the Medical Research Council and supports a default parameter that is the same as that fitted to the Western Cape experience.

3.3 Calibration for KwaZulu Natal

The reported deaths in KwaZulu Natal are compared against three scenarios for the '% population infected' parameter in the graph below. The default parameter used in the model is that 20% of the population in this province will be infected in the first wave of COVID-19 infections.

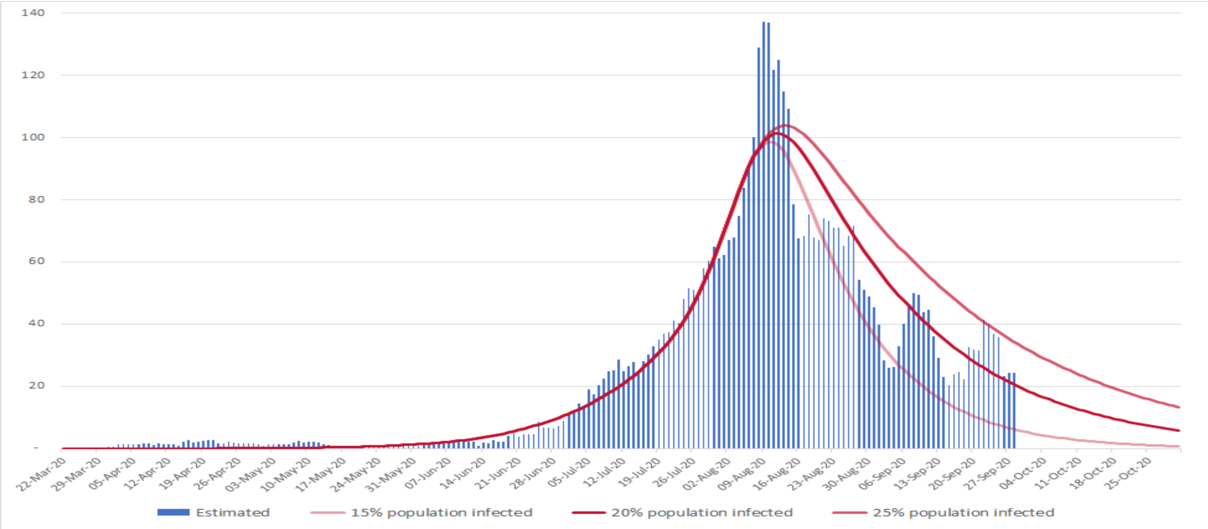

Figure 4 Forecast daily COVID-19 deaths (7-day moving average) – KwaZulu Natal

The daily reported COVID-19 deaths in KwaZulu Natal have been increased by 80% to allow for unreported deaths due to COVID-19.

3.4 Calibration for the Eastern Cape

The reported deaths in the Eastern Cape are compared against three scenarios for the '% population infected' parameter in the graph below. The default parameter used in the model is that 20% of the population in this province will be infected in the first wave of COVID-19 infections.

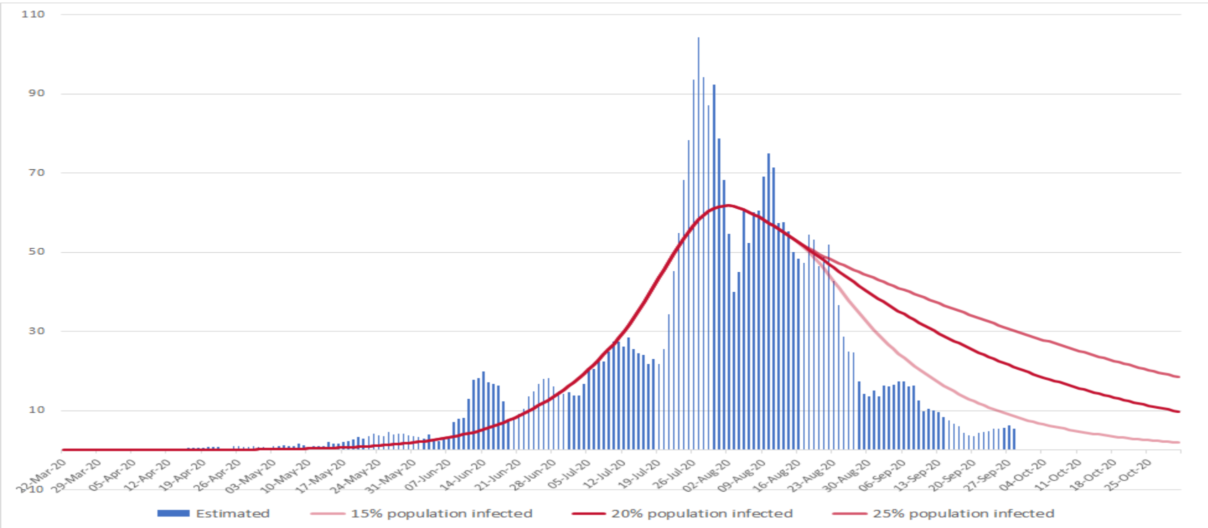

Figure 5 Forecast daily COVID-19 deaths (7-day moving average) – Eastern Cape

The daily reported COVID-19 deaths in the Eastern Cape have been increased by 10% to allow for unreported deaths due to COVID-19. This supports a default parameter that is the same as that fitted to the KwaZulu Natal experience.

3.5 Calibration for the remaining provinces

A default parameter of 25% of the population infected in the first wave of infections has been used for the Free State and 20% of the population infected for the other provinces.

4. Forecast results

NMG has released a web-based version of the multi-state actuarial model that will allow interested parties to generate different COVID-19 forecast scenarios for South Africa. The model can be accessed at https://nmg-covid-19.sctechnology.co.za/

4.1 Forecast of symptomatic infections

The symptomatic infections implied by the NMG model are plotted for the four large provinces in the table below using the default '% population infected' parameters. Only for the Western Cape, do the infections reach a plateau. The model will be adjusted if a similar plateau shape becomes evident in any of the other provinces.

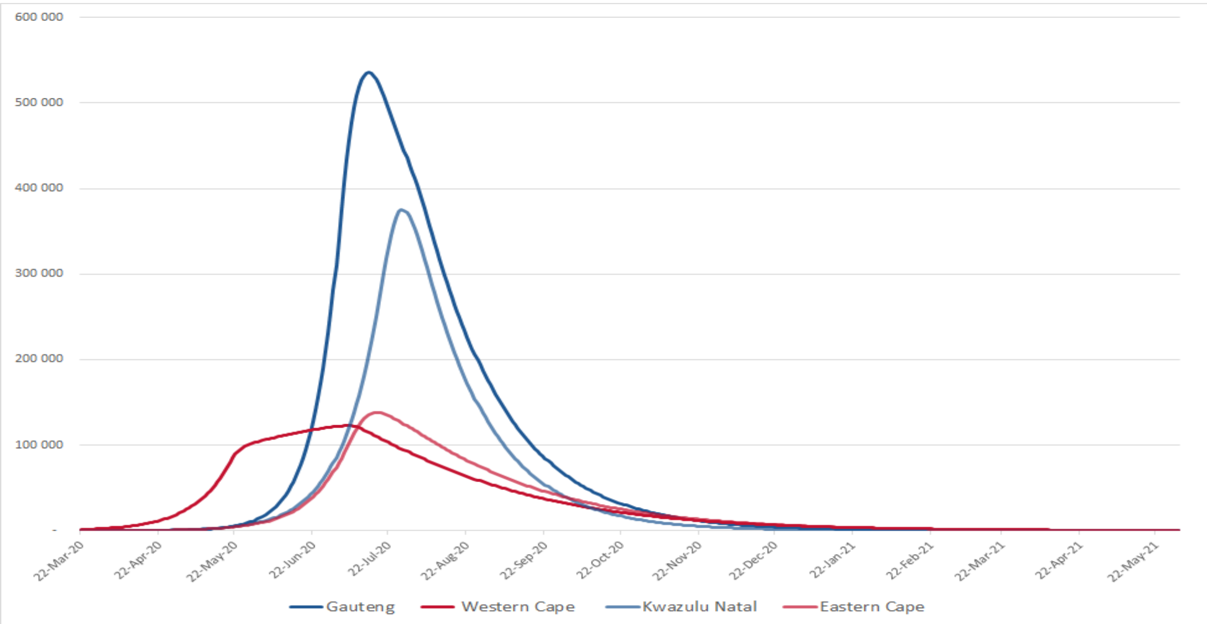

Figure 6 COVID-19 symptomatic infections projected for top four provinces

Taking an aggregate of all nine provinces provides a forecast for the aggregate of symptomatic and asymptomatic infections that shows them having already peaked. The forecast of infections for South Africa as whole is shown below:

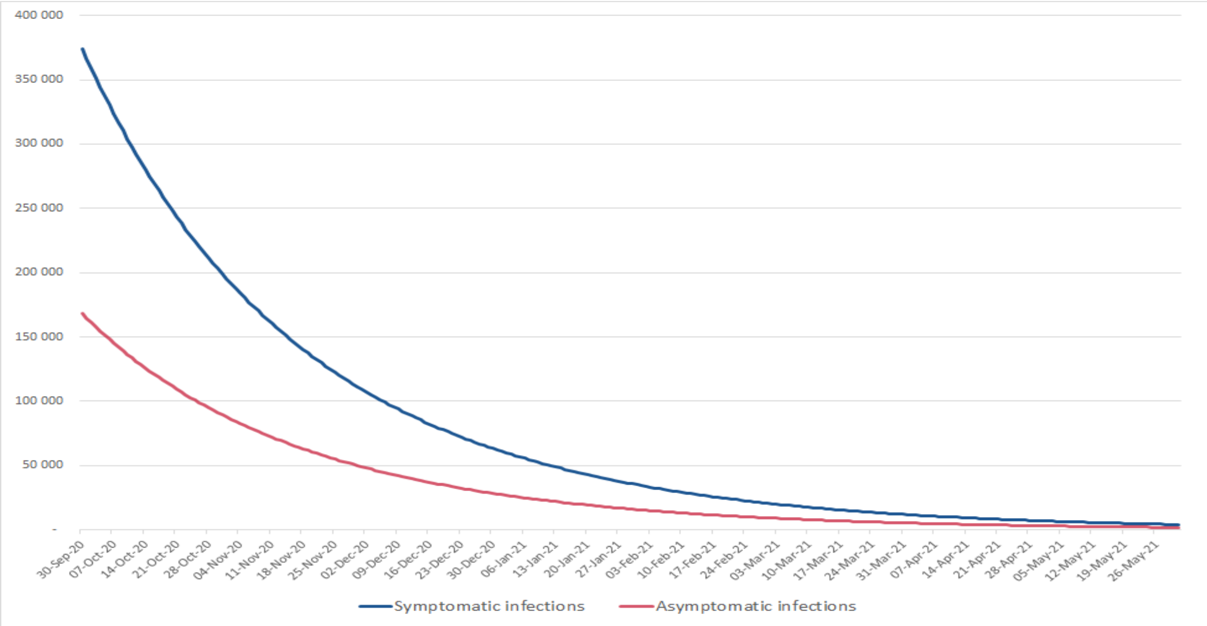

Figure 7 Forecast of reported and unreported infections

4.2 Forecast of hospital beds and deaths

The number of potential lives being treated in hospital for COVID-19 is forecast to start coming off its peak at 19 400. Based on adjusted international Infection Fatality Ratios applied at a province level and the default '% population infected' parameters, some 33 900 lives are expected to be lost due to the pandemic.

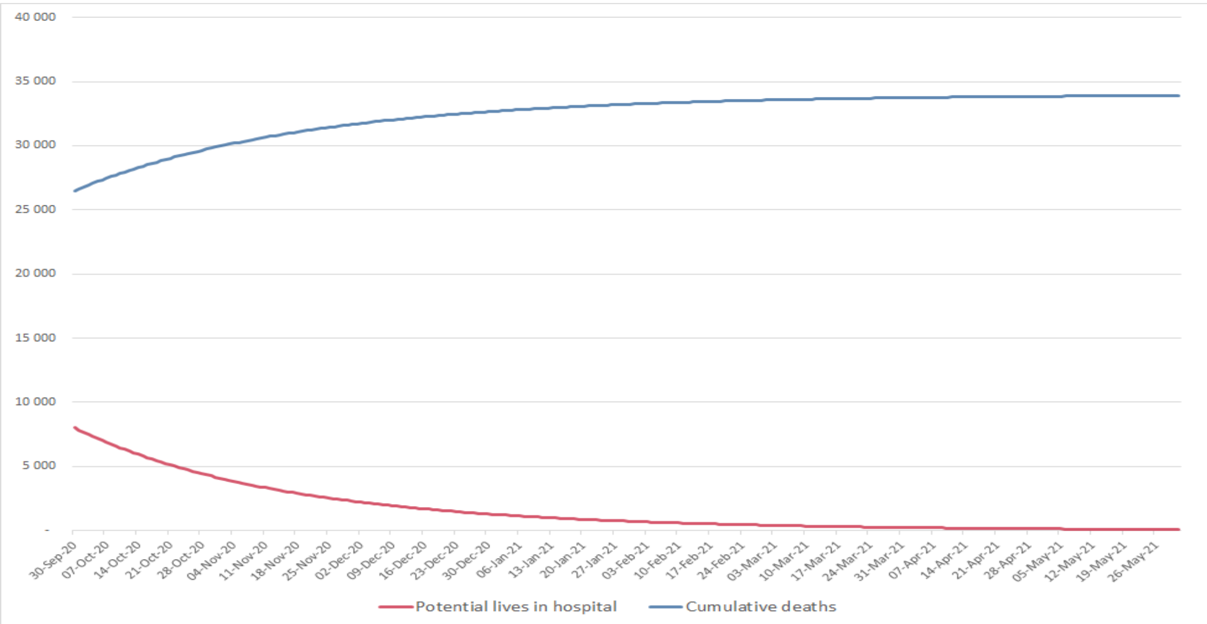

Figure 8 Forecast of hospital beds and cumulative deaths

4.3 Sensitivity analysis

The graphs below expand on how the input parameters impact of the model projection results.

The '% population infected' parameter is key to determining the number of lives in the population that will become infected by the virus in this first wave. The projected symptomatic infections are shown below for the default parameter value and values 5% less and 5% more than the default:

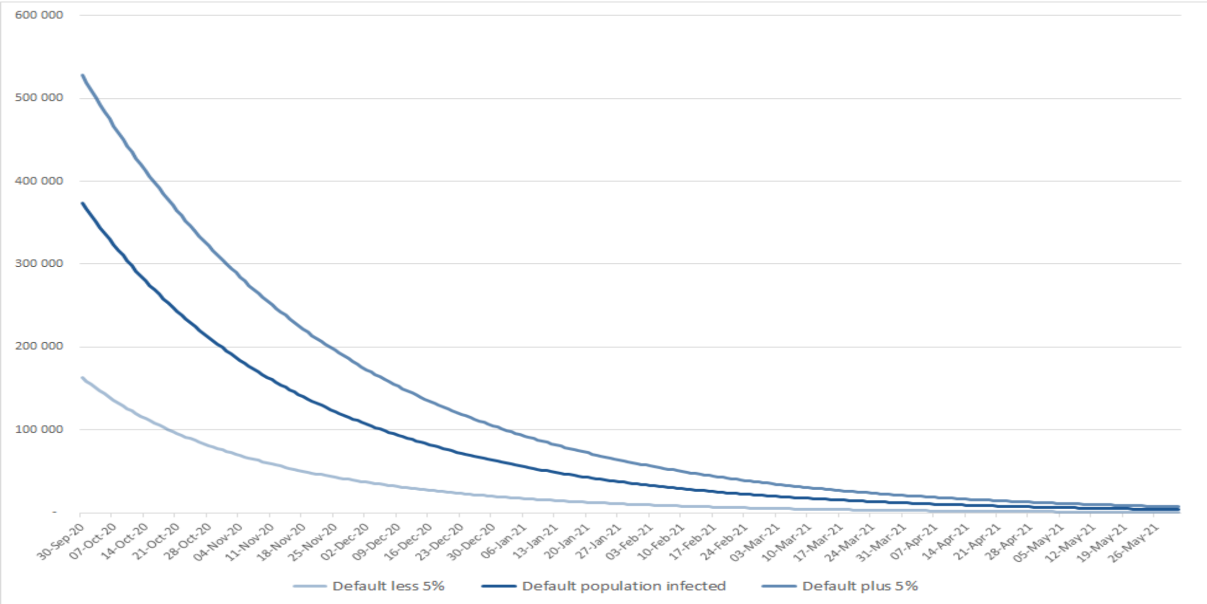

Figure 9 Forecast of COVID-19 infections (symptomatic)

The forecast cumulative COVID-19 deaths are shown below for the default parameter value for '% population infected' and values 5% less and 5% more than the default:

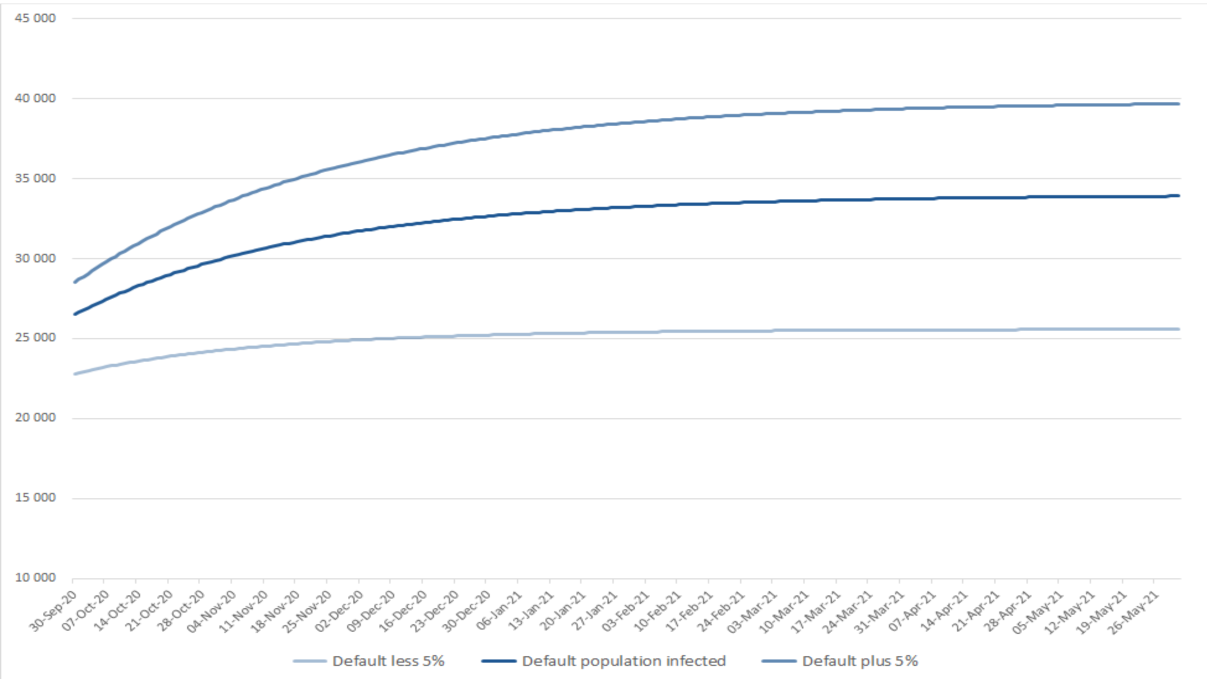

Figure 10 Forecast of cumulative COVID-19 deaths

The forecast for hospital bed days required for COVID-19 patients are shown below for the default parameter value for '% population infected' and values 5% less and 5% more than the default:

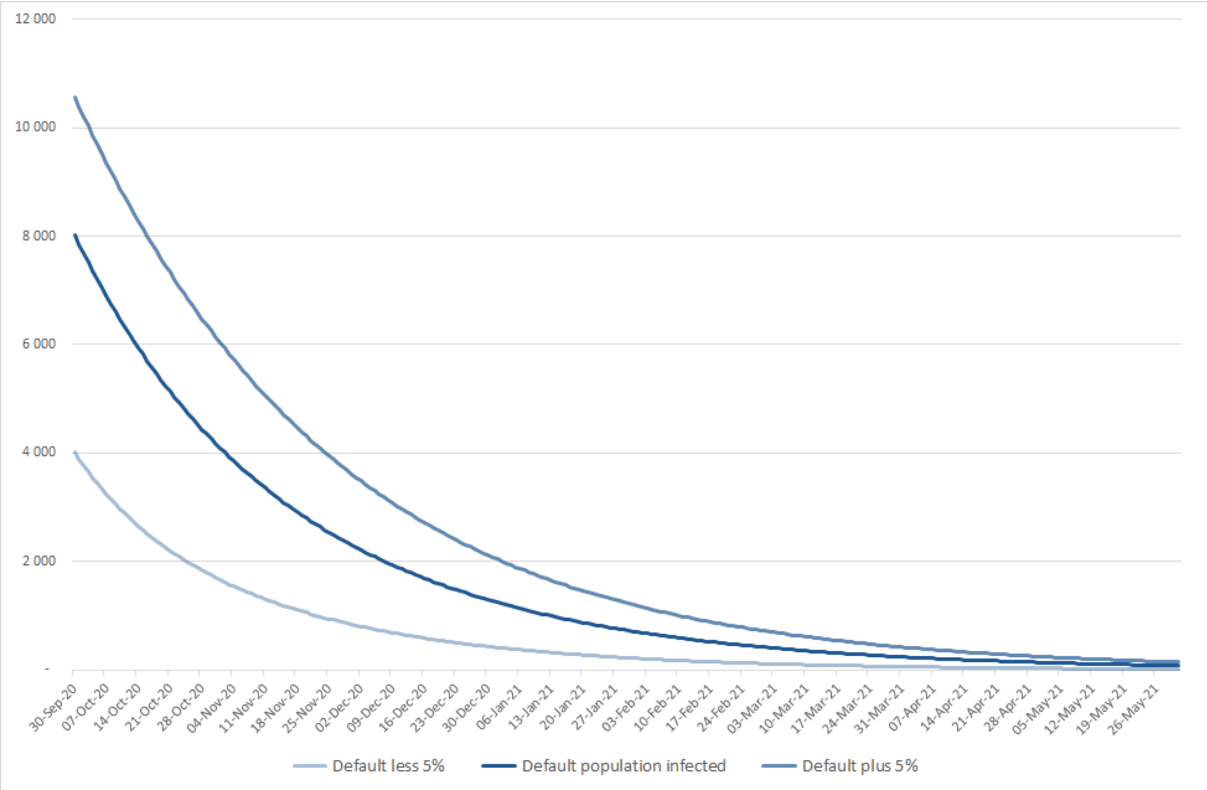

Figure 11 Forecast of potential hospital beds required due to COVID-19

5. Second wave of COVID-19 infections

The forecast results set out in Section 4 are for a first wave of COVID-19 infections. The NMG model has been extended to allow for the modelling of scenarios for a second wave of infections. Some second wave scenarios are discussed in this section of the report.

5.1 Expectations for a second wave

The default parameters applied to the NMG model forecast that 22% of the South African population will have been infected in the first wave of COVID-19 infections. With this level of seroprevalence in a population, the likelihood of a second wave of infections is low, and the intensity of a second wave, should it occur, should be dampened.

5.2 Second wave scenarios

The NMG model has been extended to allow for the modelling of scenarios for a second wave of COVID-19 infections. The graph below shows the impact of a low intensity second wave where viral propagation increases to a level represented by a reproduction number of 1.00 from 1 October 2020, along with three scenarios for a spike in infections on 15 December 2020.

The spike in infections are assumed to last for 15 days, 30 days and 45 days in the three scenarios provided. Viral propagation during the spike is assumed to increase to a level represented by a reproduction number of 2.60 in the scenarios provided.

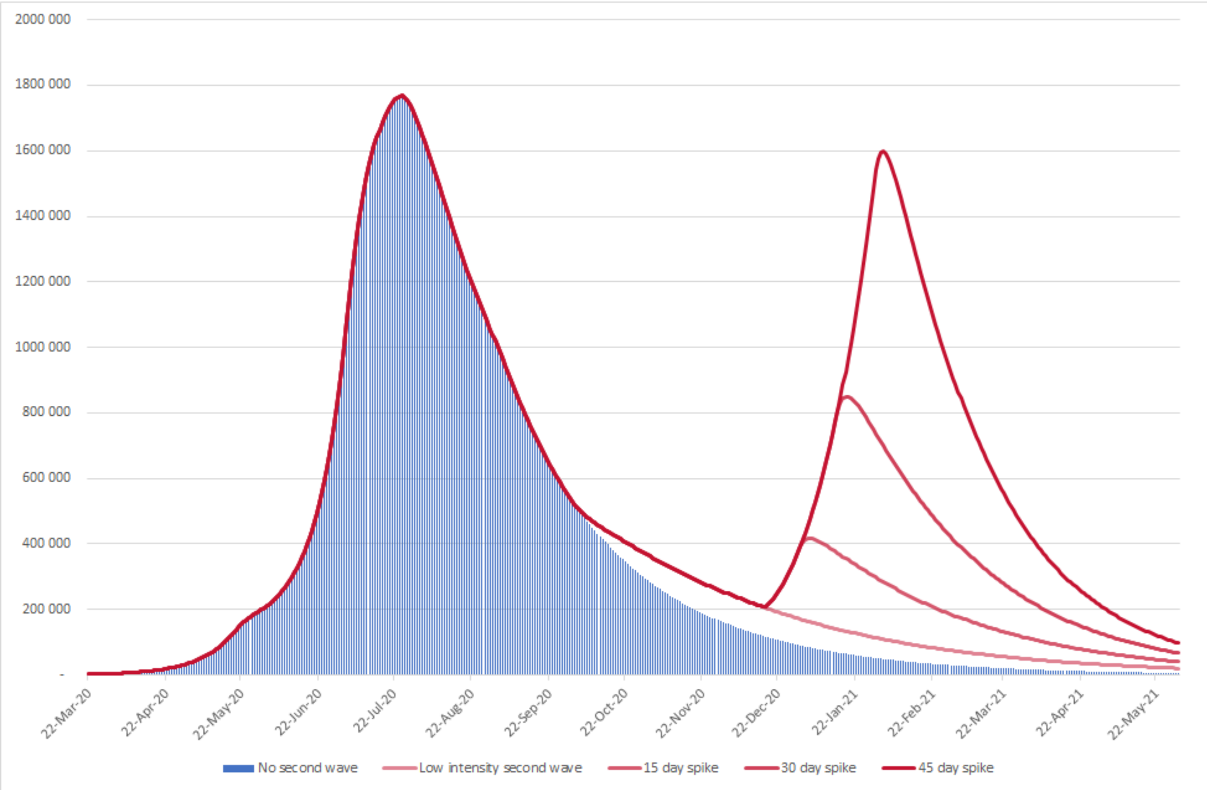

Figure 12 Forecast COVID-19 infections for four second wave scenarios for South Africa

According to the modelling, a second wave of infections of the intensity shown in the '45 day spike' scenario above would leave 36% of the South African population having been infected with COVID-19 by May 2021 with COVID-19 deaths reaching 55 000.

Thank you

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