

1 **Supplementary Materials**2 **Full list of authors**

| Name | Affiliation |
|------------------------|---|
| Lisa J White | Big Data Institute, Li Ka Shing Centre for Health Information and Discovery, Nuffield Department of Medicine, University of Oxford |
| Ricardo Águas | Mahidol-Oxford Tropical Medicine Research Unit, Faculty of Tropical Medicine, Mahidol University, Bangkok, Thailand. Nuffield Department of Medicine, University of Oxford. |
| Nathaniel Hupert | Department of Medicine, Weill Cornell Medicine, and Cornell Institute for Disease and Disaster Preparedness, Cornell University, USA |
| Rima Shretta | Nuffield Department of Medicine, University of Oxford |
| Olivier Celhay | Mahidol-Oxford Tropical Medicine Research Unit, Faculty of Tropical Medicine, Mahidol University, Bangkok, Thailand |
| Ainura Moldokmatova | Big Data Institute, Li Ka Shing Centre for Health Information and Discovery, Nuffield Department of Medicine, University of Oxford |
| Proochista Ariana | Centre for Tropical Medicine and Global Health, Nuffield Department of Medicine, University of Oxford |
| Fatima Arifi | Florida International University |
| Ali Mirzazadeh | Department of Epidemiology and Biostatistics, Institute for Global Health Sciences, University of California San Francisco, San Francisco, CA, USA |
| Hamid Sharifi | HIV/STI Surveillance Research Center, and WHO Collaborating Center for HIV Surveillance, Institute for Futures Studies in Health, Kerman University of Medical Sciences, Kerman, Iran |
| Keyrellous Adib | Independent researcher (No affiliation) |
| Wirichada Pan-ngum | Mathematical And Economic MODelling Group, Mahidol-Oxford Tropical Medicine Research Unit, Faculty of Tropical Medicine, Mahidol University, Bangkok, Thailand |
| Penny Hancock | Big Data Institute, Li Ka Shing Centre for Health Information and Discovery, Nuffield Department of Medicine, University of Oxford |
| Roberto A. Kraenkel | Institute of Theoretical Physics - São Paulo State University (UNESP) |
| Renato Mendes Coutinho | Center for Mathematics, Computation and Cognition, Federal University of ABC, Brazil |
| Caroline Franco | Institute of Theoretical Physics - São Paulo State University (UNESP) |
| Sompob Saralamba | Mathematical And Economic MODelling Group, Mahidol-Oxford Tropical Medicine Research Unit, Faculty of Tropical Medicine, Mahidol University, Bangkok, Thailand |
| Nantasit Luangasanatip | Mathematical And Economic MODelling Group, Mahidol-Oxford Tropical Medicine Research Unit, Faculty of Tropical Medicine, Mahidol University, Bangkok, Thailand |
| Sheetal Prakash Silal | Modelling and Simulation Hub, Africa (MASHA), University of Cape Town, Cape Town, South Africa |
| Jared Norman | Modelling and Simulation Hub, Africa (MASHA), University of Cape Town, Cape Town, South Africa |
| Rachel Hounsell | Big Data Institute, Li Ka Shing Centre for Health Information and Discovery, Nuffield Department of Medicine, University of Oxford |
| Sai Thein Than Tun | 1: Mathematical And Economic MODelling Group, Mahidol-Oxford Tropical Medicine Research Unit; 2: Nuffield Department of Medicine, University of Oxford |
| Yu Nandar Aung | London School of Economics |
| Bakare Emmanuel A. | Department of Mathematics, Federal University, Oye-Ekiti, Ekiti State, Nigeria. |
| Biniam Getachew | Stop Transmission of Polio Program (STOP) program, World Health Organization, Birnin Kebbi, Nigeria |
| Sandra Adele | Nuffield Department of Medicine, University of Oxford |

| | |
|-------------------------|--|
| Semeeh A. Omoleke | World Health Organization, Nigeria |
| Rashid U Zaman | Oxford Policy Management |
| Nicholas Letchford | Oxford Policy Management |
| Daniel M. Parker | Population Health and Disease Prevention; Department of Epidemiology; University of California-Irvine |
| Sunil Pokharel | Independent Researcher |
| Dipti Lata | Oxford Policy Management (OPM) Nepal |
| Siyu Chen | Nuffield Department of Medicine, University of Oxford |
| Shwe Sin Kyaw | Mahidol-Oxford Tropical Medicine Research Unit, Faculty of Tropical Medicine, Mahidol University |
| Mohammad Nadir Sahak | World Health Organization, Afghanistan |
| Inke N D Lubis | Department of Paediatrics, Faculty of Medicine, Universitas Sumatera Utara, Medan, Indonesia |
| Ivana Alona | Department of Community Medicine, Faculty of Medicine, Universitas Sumatera Utara, Medan, Indonesia |
| John Robert C. Medina | Department of Epidemiology and Biostatistics, College of Public Health, University of the Philippines Manila, Philippines |
| Chris Erwin G. Mercado | Independent Researcher |
| Sana Eyboosh | Department of Epidemiology and Biostatistics, Research Centre for Emerging and Reemerging Infectious Diseases, Pasteur Institute of Iran, Tehran, Iran |
| Ibrahim Mamadu | World Health Organization, Nigeria |
| Manar Marzouk | Valid International Ltd |
| Nicole Feune de Colombi | Nuffield Department of Medicine, University of Oxford |
| Lorena Suárez-Idueta | University College of London |
| Francisco Obando | PEAK Urban and Oxford Martin Informal Cities Programmes, COMPAS, School of Anthropology and Museum Ethnography, University of Oxford |
| Luzia Freitas | Nuffield Department of Medicine, University of Oxford |
| Michael G. Klein | Department of Marketing & Business Analytics, Lucas College and Graduate School of Business, San José State University, USA |
| David Scales | Department of Medicine, Weill Cornell Medicine, Cornell University, USA |
| Dooronbekova Aizhan | Public fund «Institution of social development» |
| Chynar Zhumalieva | Public fund «Institution of social development» |
| Aida Estebesova | USAID Mission in the Kyrgyz Republic |
| Aibek Mukambetov | Soros Foundation in the Kyrgyz Republic |
| Shamil Ibragimov | Soros Foundation in the Kyrgyz Republic |
| Aisuluu Kubatova | Public fund «Institution of social development» |
| Phetsavanh Chanthavialy | Institute of Research and Education Development, University of Health Sciences, Lao PDR |
| Amel H. Salim | Population Services International/Ethiopia |
| Sudhir Venkatesan | 1: Real World Solutions, IQVIA, 2: Department of Medical Statistics, London School of Hygiene and Tropical Medicine |
| Sarin KC | Health Intervention and Technology Assessment Program (HITAP), Ministry of Public Health, Thailand |
| Priyanka Shrestha | Independent researcher (No affiliation) |
| Sayed Ataullah Saeedzai | Ministry of Public Health, Afghanistan |
| Jenny Hsieh | School of Public Health, National Taiwan University |
| Mick Soukavong | Department of Natural Sciences, Faculty of Medicine, University of Health Sciences, Laos |
| Yuki Yunanda | Department of Community Medicine, Faculty of Medicine, Universitas Sumatera Utara, Medan, Indonesia |
| Handoyo Harsono | COVID-19 Task Force for North Sumatera province, Indonesia |
| Mahnaz Hossain Fariba | Government of People's Republic of Bangladesh (ex. Nuffield Department of Medicine, University of Oxford) |
| Viviana Mabombo | Nuffield Department of Medicine, University of Oxford |
| Nicole Advani | Nuffield Department of Medicine, University of Oxford |
| Nusrat Jabin | Nuffield Department of Medicine, University of Oxford |

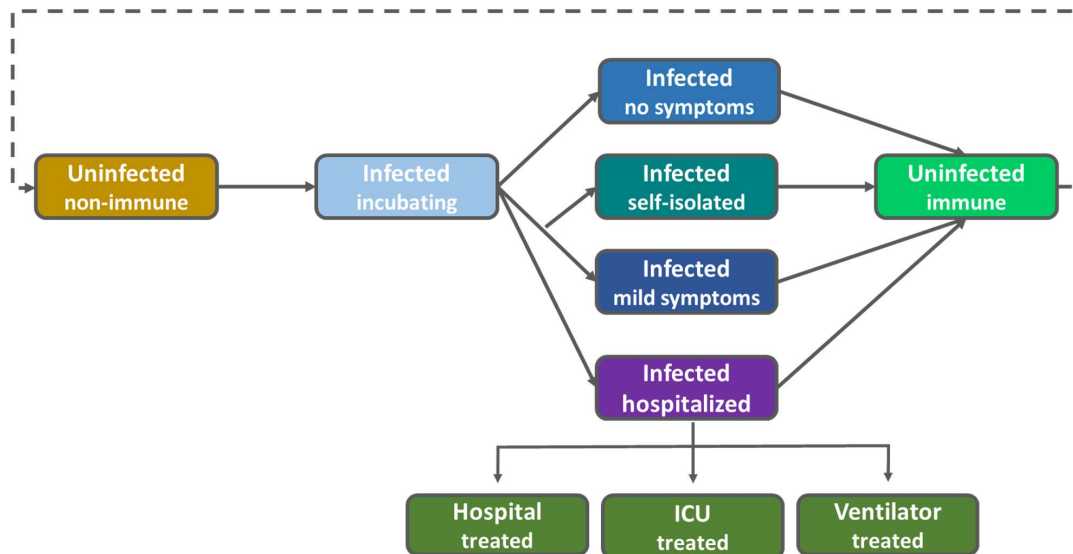
| | |
|----------------------|---|
| Reshania Naidoo | Center for Tropical Medicine and Global Health, Nuffield Department of Medicine, University of Oxford |
| Parinda Wattanasri | Nuffield Department of Medicine, University of Oxford |
| Amen-Patrick Nwosu | Nuffield Department of Medicine, University of Oxford |
| Sopuruchukwu Obiesie | Center for Tropical Medicine and Global Health, Nuffield Department of Medicine, University of Oxford |

3

4 Mathematical Model

5 The CoMo Consortium SARS-CoV-2 model is an age-structured SEIR model with infected
6 compartments stratified by symptoms, severity and treatment seeking and access. The
7 progression of individuals through the infection life cycle is represented by the diagram
8 below.

9



10

11 *Figure S1: A diagram of the baseline model structure representing the unmitigated epidemic*
12 *spread scenario*

13

14 As individuals are infected, they transit through an incubation phase at the end of which they
15 are fully infectious. At the end of this incubation period, individuals display very different
16 symptomatology, with some never having any symptoms, while others require
17 hospitalisation. If a person is hospitalised, the model tracks their health care requirements
18 (surge care bed, ICU bed, ventilator). Disease-induced mortality rates are heavily dependent
19 on how severe the infection outcome is and whether individuals can receive the appropriate
20 treatment. The model assumes that those who recover from infection will become immune.

21 We allow for loss of immunity in the model but for the moment have set this parameter to be
 22 in the order of years. The equations for the basic model structure without non-
 23 pharmaceutical (NP) interventions follow

24

25

26

$$27 \quad \frac{dS}{dt} = -S \circ \Lambda + \omega R + A \cdot S - \mu \cdot S + bP$$

$$28 \quad \frac{dE}{dt} = S \circ \Lambda - \gamma E + A \cdot E - \mu \cdot E$$

$$29 \quad \frac{dI}{dt} = \gamma (1 - p_{clin})(1 - p_{ihr}) \cdot E - \nu_I I + A \cdot I - \mu \cdot I$$

$$30 \quad \frac{dC}{dt} = \gamma p_{clin}(1 - p_{ihr}) \cdot E - \nu_I C + A \cdot C - \mu \cdot C$$

$$31 \quad \frac{dR}{dt} = \nu_I(I + C) + A \cdot R - \omega R - \mu \cdot R + (1 - \delta_H p_{hfr}) \nu_H \cdot H + (1 - \delta_{H_c} p_{hfr}) \nu_H \cdot H_c$$

$$32 \quad + (1 - \delta_U p_{hfr}) \nu_U \cdot U + (1 - \delta_{U_c} p_{hfr}) \nu_U \cdot U_c + (1 - \delta_V p_{hfr}) \nu_V \cdot U_{cv}$$

$$33 \quad + (1 - \delta_V p_{hfr}) \nu_V \cdot V + (1 - \delta_{V_c} p_{hfr}) \nu_V \cdot V_c$$

$$34 \quad \frac{dH}{dt} = p_{ihr}(1 - p_U)(1 - p_{K_H}) \gamma E - \nu_H H + A \cdot H - \mu \cdot H$$

$$35 \quad \frac{dH_c}{dt} = p_{ihr}(1 - p_U) p_{K_H} \gamma E - \nu_H H_c + A \cdot H_c - \mu \cdot H_c$$

$$36 \quad \frac{dU}{dt} = p_{ihr} p_U (1 - p_{K_U}) (1 - p_V) \gamma E - \nu_U U + A \cdot U - \mu \cdot U$$

$$37 \quad \frac{dU_c}{dt} = p_{ihr} p_U p_{K_U} (1 - p_V) \gamma E - \nu_U U_c + A \cdot U_c - \mu \cdot U_c$$

$$39 \quad \frac{dU_{cv}}{dt} = p_{ihr} p_U p_{K_U} p_V \gamma E - \nu_U U_{cv} + A \cdot U_{cv} - \mu \cdot U_{cv}$$

$$40 \quad \frac{dV}{dt} = p_{ihr} p_U (1 - p_{K_U}) (1 - p_{K_V}) p_V \gamma E - \nu_V V + A \cdot V - \mu \cdot V$$

$$41 \quad \frac{dV_c}{dt} = p_{ihr} p_U (1 - p_{K_U}) p_{K_V} p_V \gamma E - \nu_V V_c + A \cdot V_c - \mu \cdot V_c$$

$$42 \quad P = (S + E + I + C + R + H + H_c + U + U_c + U_{cv} + V + V_c)$$

$$43 \quad s = 1 + a \cos \left(2\pi \frac{\left(t - \left(\frac{365.25\phi}{12} \right) + t_{in} \right)}{365.25} \right)$$

$$44 \quad W = W_{home} + W_{work} + W_{school} + W_{oth}$$

$$45 \quad \Lambda = p s W \cdot \left(\frac{\rho E + I + C + \rho_s * (H + H_c + U + U_c + U_{cv} + V + V_c)}{P} \right)$$

$$46 \quad A = \begin{pmatrix} \begin{pmatrix} -\alpha & 0 \\ \alpha & -\alpha \end{pmatrix} & \dots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \dots & \begin{pmatrix} -\alpha & 0 \\ \alpha & 0 \end{pmatrix} \end{pmatrix}$$

38

47

$$p_{K_H} = \begin{cases} 0 & \text{for } H < K_H \\ 1 & \text{for } H \geq K_H \end{cases}$$

$$p_{K_U} = \begin{cases} 0 & \text{for } U < K_U \\ 1 & \text{for } U \geq K_U \end{cases}$$
$$p_{K_V} = \begin{cases} 0 & \text{for } V < K_V \\ 1 & \text{for } V \geq K_V \end{cases}$$

50

51 The model uses publicly available country-specific data to define the population structure¹,
52 as a model input. A description of the variables used can be found in Table S1 and a list with
53 all parameters included in the full model including non-pharmaceutical (NP) interventions is
54 given in Table S2.

55

56 The model interface can be found here: <https://comomodel.net/>. The model interface uses
57 publicly available country-specific data on cases and mortality for COVID-19¹ for visual
58 calibration of model parameters to user-selected baseline scenarios. More elaborate
59 calibration methods are under consideration but are not considered to be a priority since the
60 system is unidentifiable and therefore calibration will be entirely dependent on user-selected
61 baseline scenarios.

62

63 Non-pharmaceutical interventions

64 A series of non-pharmaceutical interventions were included in the model; these can be
65 switched on for specific periods of time, thus building a bespoke intervention package.

66

67 Self-Isolation if Symptomatic

68 This is the practice of individuals with either a confirmed case of Covid-19 or with Covid-19
69 symptoms isolating themselves at home for a period of 7 days. The parameters governing this
70 intervention are:

- 71 • Start Date: the start date of the protocol
- 72 • Duration: the duration of the protocol
- 73 • Coverage: the percentage of the population who will be able to self-isolate if they have
74 symptoms or are a confirmed case
- 75 • Adherence: the percentage of the designated isolation period that self-isolated
76 individuals adhere to the intervention

77

78 Screening

79 This is a form of contact-tracing. Given enough testing capacity, it reflects how suspected
80 contacts of confirmed cases are tested using a SARS-CoV-2 virological test. All individuals who
81 test positive are then requested to self-isolate

- 82 • Start Date: the start date of additional screening
- 83 • Test Sensitivity: Probability that an infected person will test positive when screened
- 84 • Suspected Contacts: number of people screened per reported case
- 85 • Overdispersion: informs the probability of finding an infected person that is a known
86 contact of a reported case, relative to random sampling (overdispersion = 1)

- 87 • Duration: duration of this additional protocol

88

89 Physical Distancing

90 Also known as physical distancing, this refers to the measures taken to prevent the spread of
91 a contagious disease by maintaining a specific physical distance between individuals and
92 reducing the number of times individuals come into close contact with each other. The
93 parameters governing this intervention are:

- 94 • Start Date: the start date of the protocol
95 • Duration: the duration of the protocol
96 • Coverage: the percentage of the population who reduce their societal contacts
97 (excluding those at home, work and school)
98 • Adherence: the percentage of the time that those practicing physical distancing
99 adhere to physical distancing measures

100

101 Handwashing

102 This indicates improvements in personal hygiene and reduction in risk behaviours (touching
103 the face, nose or mouth), including the adoption of personal protective equipment such as
104 masks. The parameters governing this intervention are:

- 105 • Start Date: the start date of the protocol
106 • Duration: the duration of the protocol
107 • Efficacy: the effectiveness of personal hygiene measures in reducing the risk of
108 infection per contact

109

110 Working at Home

111 This indicates the effect of having workers working from home. The parameters governing
112 this intervention are:

- 113 • Start Date: the start date of the protocol
114 • Duration: the duration of the protocol
115 • Efficacy: the percent reduction in work related contacts
116 • Home contacts inflation: the percent increase in the numbers of home contacts due
117 to increased number of hours spent at home

118

119 School Closures

120 This indicates school closures and assumes that all schools in a country close at the same time.
121 The parameters governing this intervention are:

- 122 • Start Date: the start date of the protocol
123 • Duration: the duration of the protocol
124 • Efficacy: defined as the percent reduction in contacts between school children when
125 schools are closed

- 126 • Home contacts inflation: the percent increase in the numbers of home contacts due
127 to increased numbers of hours spent at home
128

129 Shielding the Elderly

130 This intervention is designed to isolate a proportion of the elderly population and reduce their
131 overall contacts. The parameters governing this intervention are:

- 132 • Start Date: the start date of the protocol
133 • Duration: the duration of the protocol
134 • Coverage: the percentage of the elderly population who are shielded
135 • Efficacy: defined as the percent reduction in overall contacts of the shielded elderly
136 population
137 • Minimum age for elderly cocoon: the minimum age cut-off defining which people
138 should protect themselves
139

140 Travel Ban

141 This refers to a ban on international travel. The parameters governing this intervention are:

- 142 • Start Date: the start date of the protocol
143 • Duration: the duration of the protocol
144 • Efficacy: the percent reduction in imported cases per day
145

146 Voluntary home quarantine

147 This indicates how many people will voluntarily quarantine themselves at home for a specified
148 number of days if a person they live with tests positive for Covid-19. The parameters
149 governing this intervention are:

- 150 • Start Date: the start date of the protocol
151 • Duration: the duration of the protocol
152 • Days in quarantine for an average person
153 • Coverage: The percentage of people voluntarily quarantining themselves given they
154 live with a known infectious case
155 • Rate: Speed at which people decide to quarantine themselves if they live with a known
156 infectious case
157 • Percent decrease in the number of other contacts when voluntarily quarantining:
158 refers to decreased mean numbers of contacts outside of the home while
159 quarantining
160 • Percent increase in the number of contacts at home when voluntarily quarantining:
161 refers to increased numbers of home contacts due to increased time spent at home
162 while quarantining
163

164 Lockdown

165 This refers to an emergency protocol that is categorised into three levels based on the efficacy
166 or coverage of the various non-pharmaceutical interventions. The parameters governing this
167 intervention are:

- 168 • Low-level lockdown (self-isolation 50%, physical distancing 25%, cocoon 95%, hand-
169 hygiene 5%)
 - 170 ○ Start Date: the start date of mid-level lockdown protocols
 - 171 ○ Duration: the duration of mid-level lockdown protocols
- 172 • Mid-level lockdown (self-isolation 50%, physical distancing 95%, school closure 85%,
173 travel ban 95%, voluntary home quarantine 5%, working from home 50%, cocoon 95%,
174 hand-hygiene 5%)
 - 175 ○ Start Date: the start date of low-level lockdown protocols
 - 176 ○ Duration: the duration of low-level lockdown protocols
- 177 • High-level lockdown (self-isolation 95%, physical distancing 35%, school closure 85%,
178 voluntary home quarantine 90%, working from home 75%, cocoon 95%, hand-hygiene
179 7.5%)
 - 180 ○ Start Date: the start date of high-level lockdown protocols
 - 181 ○ Duration: the duration of high-level lockdown protocols

182

183

184

185

186 Table S1. Description of the model variables.

| Symbol | Definition |
|-----------------|--|
| S | Susceptible |
| E | Infected and incubating |
| I | Infectious and asymptomatic following incubation |
| C | Infectious and mildly symptomatic following incubation |
| R | Recovered and immune |
| H | Severe infection: hospitalised |
| H _c | Severe infection: not hospitalised due to lack of capacity |
| U | Severe infection: hospitalised in ICU |
| U _c | Severe infection: hospitalised and requiring ICU but placed in surge ward |
| U _{cv} | Severe infection: hospitalised and requiring ventilator but placed in surge ward |
| V | Severe infection: hospitalised in ICU and on a ventilator |
| V _c | Severe infection: hospitalised in ICU requiring a ventilator but not on one |

187

188

189 Table S2. A list of the default parameter values used. These are subject to change when the
 190 model is applied to a new setting and/or with new incoming information. We have provided
 191 references to demonstrate that the default values lie within plausible ranges. † Country-
 192 specific value; ‡Assumed value (no reference found).

| Symbol | Definition | Value | Unit | Source |
|-------------------------------------|---|-------|--------------------|--------------------------|
| Demographics | | | | |
| W_{home} | Country-specific age-dependent contact matrix describing the number of potentially infectious contacts at home per person per day | † | day ⁻¹ | ² |
| W_{work} | Country-specific age-dependent contact matrix describing the number of potentially infectious contacts at work per person per day | † | day ⁻¹ | ² |
| W_{school} | Country-specific age-dependent contact matrix describing the number of potentially infectious contacts at school per person per day | † | day ⁻¹ | ² |
| W_{other} | Country-specific age-dependent contact matrix describing the number of potentially infectious societal contacts per person per day | † | day ⁻¹ | ² |
| μ | 1/Age-dependent non-Covid-19-related death rate | † | days | ³ |
| b | 1/ Age-dependent fertility rate | † | days | ³ |
| α | Ageing rate between age categories | 0.2 | year ⁻¹ | |
| Natural history of infection | | | | |
| p | Probability of infection given a single contact | † | NA | ⁴ |
| γ | 1/duration of incubation period | 3.5 | days | ⁵⁻⁷ |
| ρ | Relative infectiousness of incubating phase | 0.1 | NA | ‡ |
| p_{clin} | Proportion of all infections that ever develop symptoms | 0.55 | NA | ⁸⁻¹⁰ |
| ν_I | 1/duration of infectious phase post incubation | 4.5 | days | ⁵ |
| ρ_s | Relative proportion of contacts for hospitalised patients | 0.15 | NA | ‡ |
| ω | 1/duration of immunity | 150 | years | ‡ |
| Seasonality | | | | |
| a | Relative variation in viral transmissibility throughout the year (+- a proportion) | † | NA | - |
| ϕ | Month of peak in transmissibility | † | NA | - |
| Patient outcomes | | | | |
| p_{ihr} | Probability of an infection being severe (requiring hospitalisation) by age | † | NA | ^{3 11-14} |
| p_{hfr} | Probability of a severe/hospitalised infection being fatal by age | † | NA | ^{3 11 12 14 15} |
| ν_H | 1/Duration of hospitalised infection | † | days | ¹⁶ |
| ν_U | 1/Duration of ICU infection | † | days | ^{17 18} |

| | | | | |
|----------------|--|------|------|--------|
| ν_V | 1/Duration of ventilated infection | † | days | 5 6 15 |
| δ_H | Maximum probability of death for a hospitalised infection | 0.35 | | 3 16 |
| δ_{H_c} | Maximum probability of death for an infection requiring hospitalisation that did not receive appropriate treatment | 0.45 | NA | 19 |
| δ_U | Maximum probability of death for a hospitalised infection requiring ICU admission | 0.55 | NA | 19 20 |
| δ_{U_c} | Maximum probability of death for a hospitalised infection that would require ICU admission but was not admitted to the ICU | 0.8 | NA | 19 |
| δ_V | Maximum probability of death for a hospitalised infection requiring a ventilator | 0.8 | NA | 19 |
| δ_{V_c} | Maximum probability of death for a hospitalised infection that would require a ventilator but did not get one | 0.95 | NA | 21 |
| p_U | Probability of an infected patient needing ICU | 0.5 | NA | 13 21 |
| p_V | Probability of an infected patient needing ICU and a ventilator | 0.75 | NA | 21 |
| K_H | Standard hospital bed capacity | † | NA | - |
| K_U | ICU bed capacity | † | NA | - |
| K_V | Ventilator capacity | † | NA | - |

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