Predicting the impact of vaccination strategies in the COVID-19 pandemic using a Susceptible-Exposed-Infectious-Removed model

Wei Song[1,2], Yunni Yi[1]

[1]Adelphi Values PROVE, Bollington, Cheshire SK10 5JB, United Kingdom, [2] University of York, York, United Kingdom

Adelphi ADELPHI VALUES | PROVE Expertise in Access and Value Evidence Outcomes

PN20

Virtual ISPOR 2021

Introduction

> Coronavirus (COVID-19) has resulted in over 159.38 million infections and 3.31 million deaths world-wide and both figures are still increasing.

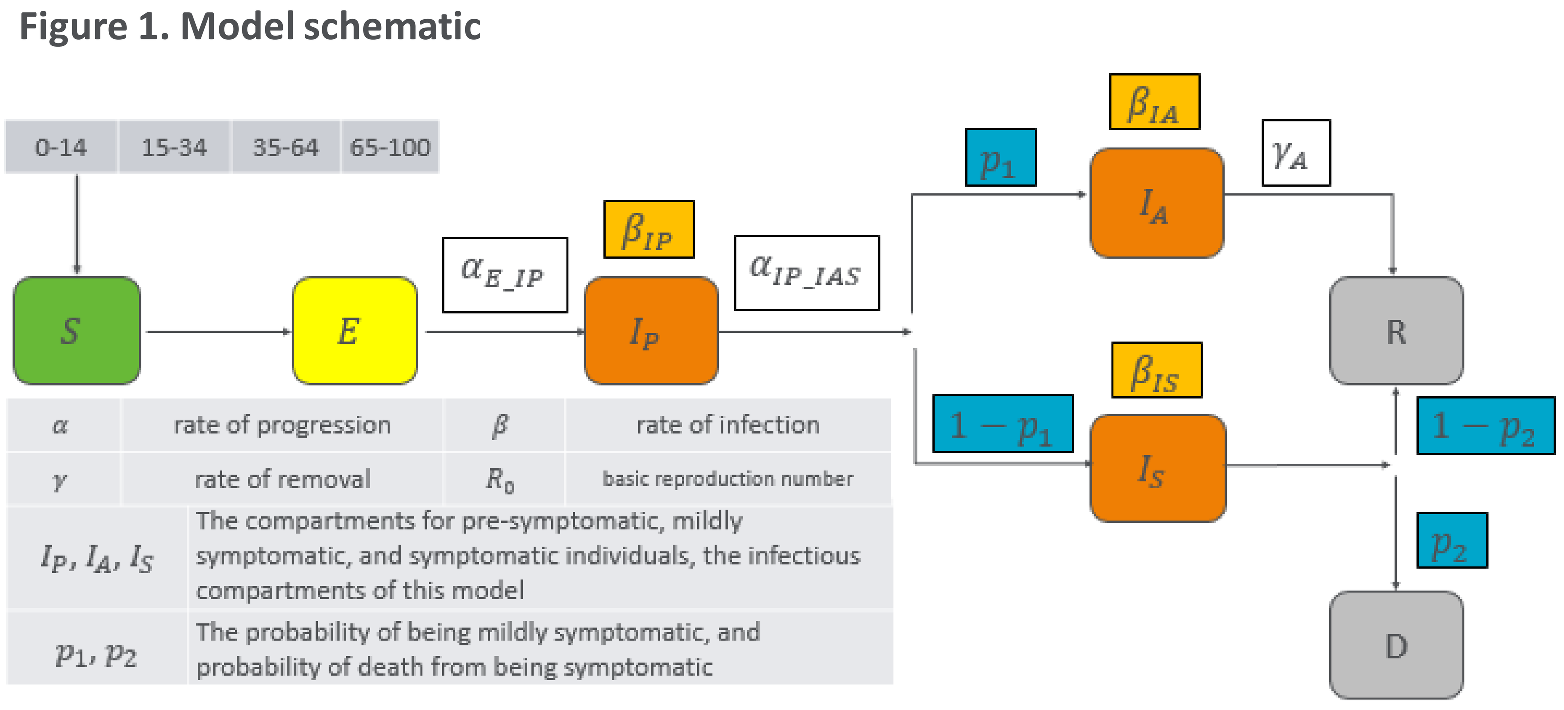
> In spite of measures such as social distancing and lockdowns, vaccines provide best protection against the spread of the disease. However, vaccine supply is limited. Therefore, setting out a vaccination strategy based on cost-effective prioritisation of specific population sub-groups is paramount.

> Using a Susceptible-Exposed-Infectious-Removed (SEIR) model, this study aimed to predict the impact of different vaccination strategies in the UK on mortality, productivity loss, and healthcare burden.

Methods

> A SEIR model was built in R using the UK estimated age-group specific proportions of asymptomatic infections, probability of severe symptoms and death rate from published literature.

Figure 1. Model schematic



> Key parameters guiding individuals moving through the model were calculated using the formulas below:

$$R_0 = \frac{\beta_{IP}}{\alpha_{IP\_IAS}} + p_1 \frac{\beta_{IA}}{\gamma_A} + (1-p_1)\frac{\beta_{IS}}{\gamma_S}$$

$$\beta_{IP} = n\beta_{IS} \quad \beta_{IA} = m\beta_{IS} \quad \beta_{IS} = R_0 \frac{\alpha_{IP\_IAS}\,\gamma_A\,\gamma_S}{n\,\gamma_A\,\gamma_S + p_1\,m\,\alpha_{IP\_IAS}\,\gamma_S + (1-p_1)\,\alpha_{IP\_IAS}\,\gamma_A}$$

> Assuming vaccine supply covers 20% or 50% of the UK population as two base scenarios, three population-wide vaccination strategies with different age group priorities were modelled.

> Hospitalisation costs were considered including critical and non-critical care for symptomatic patients, with different service utilisation and length of stay. NHS reference costs were used.

> Quality-adjusted life year (QALY) losses from death were estimated through the standard life table approach with quality adjustment and discounting.

> For each scenario, total number of infections, COVID-19 related deaths, QALYs lost, cost for critical and non-critical care, and productivity loss were estimated.

Results

> Under the 20% vaccine supply scenario, the model favours vaccinating the 15-34 age group (B1) first when considering only the total number of infections.

> When compared against the strategy of vaccinating the 64+ age group first, vaccinating the younger cohort prevented an additional 2 million infections (3% of total population).

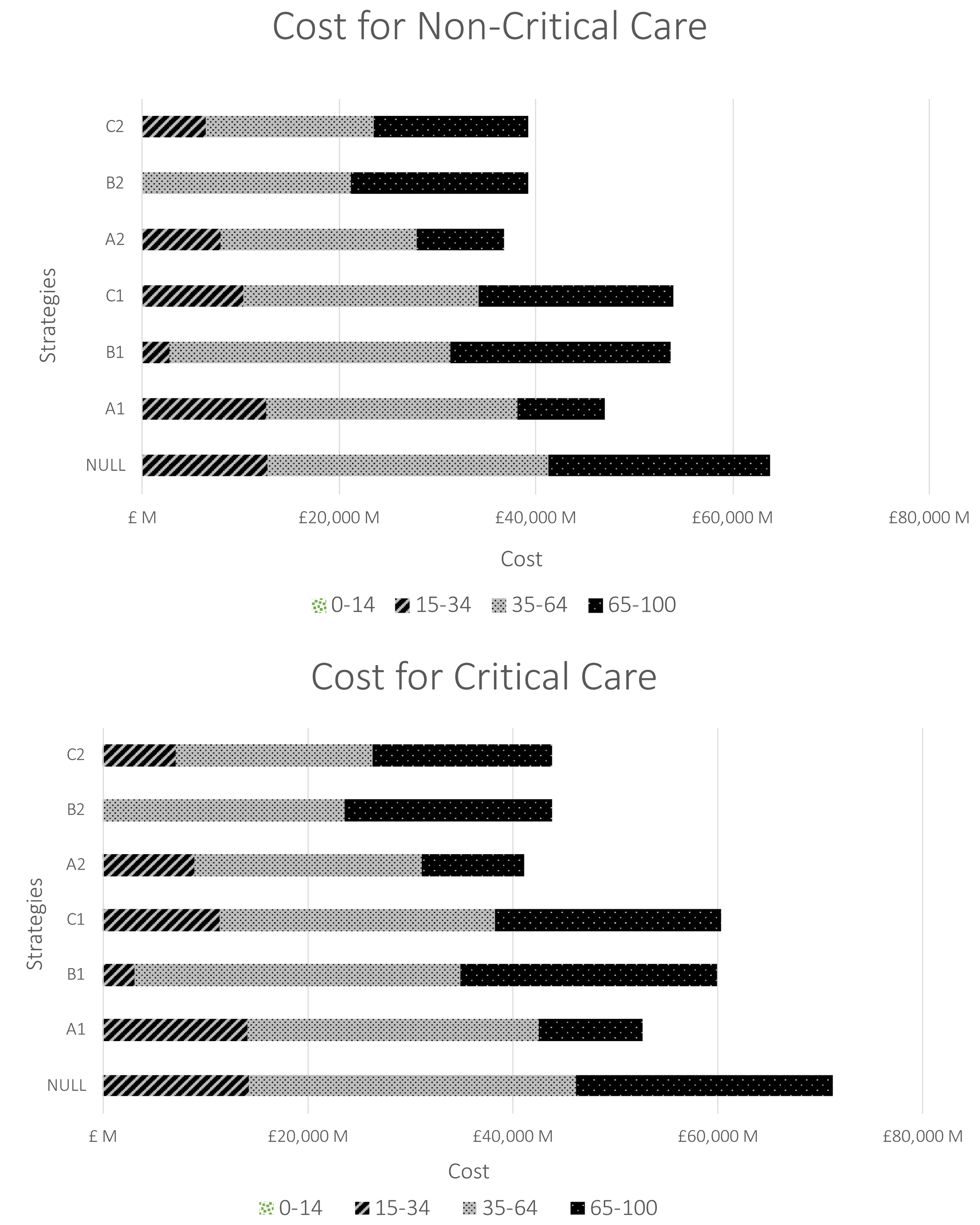
Table 1. Main model output

	Strategies	SEIR			Hospitalisation cost			QALY loss from death
		Number of infections	Number of deaths	Productivity loss (person-day)	Non-critical care	Critical care	Total hospitalisation cost	
	NULL	63,712 K	2,669 K	209,241 K	£63,730 M	£71,197 M	£136,262 M	31,222 K
20% initial vaccine availability	A1 vaccination coverage of the elderly age group (65 and above)	53,905 K	1,779 K	195,322 K	£47,047 M	£52,559 M	£100,495 M	25,440 K
	B1 vaccination coverage of the young age group (15-34)	50,910 K	2,390 K	137,554 K	£53,654 M	£59,940 M	£114,789 M	24,758 K
	C1 vaccination coverage spread proportionally across age groups.	52,848 K	2,280 K	172,133 K	£53,920 M	£60,238 M	£115,298 M	26,159 K
50% initial vaccine availability	A2 vaccination coverage of the elderly age group (65 and above)	38,918 K	1,450 K	139,069 K	£36,815 M	£41,129 M	£78,669 M	19,223 K
	B2 vaccination coverage of the young age group (15-34)	35,102 K	1,797 K	87,642 K	£39,161 M	£43,750 M	£83,810 M	17,463 K
	C2 vaccination coverage spread proportionally across age groups.	36,553 K	1,696 K	116,470 K	£39,206 M	£43,799 M	£83,852 M	18,565 K

Results

> When considering the cost of hospital care, vaccinating the 65+ age group (strategy A1) is preferred, resulting in a £6.61 billion (13%) reduction in costs from non-critical and critical care, as well as death-related hospital costs.

Figure 2. Cost for critical care and non-critical care (at 20% and 50% initial supply based on the strategy)



> When considering age group specific hospital costs, the 35-64 age group was found to represent approximately 45% of hospital costs when no vaccination was provided. This age group was associated with between 43%-54% of hospital costs with different vaccination strategies.

> Vaccinating the 65+ age group first significantly lowered hospital costs, from 35% to 19% when comparing no vaccination and strategy A1.

> Productivity and QALY losses were minimized by prioritizing the 15-34 age group, while vaccinating those over 65 first resulted in the lowest number of deaths.

> Increasing population coverage from 20% to 50% resulted in decreased QALY losses and healthcare burden. However, the choice of vaccination strategy was not affected.

> Threshold analysis suggested a strategy that prioritises elderly vaccination would minimise QALY losses only if the death rate amongst 15-34s dropped by 17.4% (from 10.9% to 9%).

Conclusions

> Compartmental models have been widely applied in the field of infectious disease modelling. This study explored its application in health economic evaluations of vaccination policies.

> With constraints in vaccine supplies, a vaccination strategy prioritising older age groups was associated with greater reductions in COVID-19 related hospitalisation costs and deaths.

> Lower QALY and productivity losses were associated with a vaccination strategy prioritising younger cohorts (15-34 years of age).

> One of the limitations of this research is the lack of reliable age group specific case fatality rate, as the Office for National Statistics (ONS) COVID-19 deaths statistics were used.

> The model did not consider non-pharmacological interventions (NPIs), nor did it consider virus mutation and possible implications for long-term immunity achieved with vaccination.

> In ranking strategies, outcome domains as reported were considered separately. However, in reality, vaccination strategies need to account for multiple attributes simultaneously. This can be achieved through multi-criteria decision analysis.

Briggs, A.H., Goldstein, D.A., Kirwin, E., Meacock, R., Pandya, A., Vanness, D.J. and Wisløff, T., 2021. Estimating (quality-adjusted) life-year losses associated with deaths: With application to COVID-19. *Health Economics*, *30*(3), pp.699-707.

Colbourn, T., Waites, W., Panovska-Griffiths, J., Manheim, D., Sturniolo, S., Colbourn, G., Bowie, C., Godfrey, K.M., Peto, J., Burgess, R.A. and Foster, D., 2020. Modelling the health and economic impacts of population-wide testing, contact tracing and isolation (PTTI) strategies for COVID-19 in the UK.

Docherty, A.B., Harrison, E.M., Green, C.A., Hardwick, H.E., Pius, R., Norman, L., Holden, K.A., Read, J.M., Dondelinger, F., Carson, G. and Merson, L., 2020. Features of 20 133 UK patients in hospital with covid-19 using the ISARIC WHO Clinical Characterisation Protocol: prospective observational cohort study. bmj, 369.

Ferguson, N., Laydon, D., Nedjati Gilani, G., Imai, N., Ainslie, K., Baguelin, M., Bhatia, S., Boonyasiri, A., Cucunuba Perez, Z.U.L.M.A., Cuomo-Dannenburg, G. and Dighe, A., 2020. Report 9: Impact of non-pharmaceutical interventions (NPIs) to reduce COVID19 mortality and healthcare demand.