Review

# Role of modelling in COVID-19 policy development

Emma S. McBryde [a,*], Michael T. Meehan [a], Oyelola A. Adegboye [a], Adeshina I. Adekunle [a],
Jamie M. Caldwell [b], Anton Pak [a], Diana P. Rojas [b], Bridget M. Williams [c], James M. Trauer [c]

[a] Australian Institute of Tropical Health and Medicine, James Cook University, Australia
[b] Department of Biology, University of Hawaii at Manoa, United States of America
[c] Epidemiological Modelling Unit, School of Public Health and Preventive Medicine, Monash University, Australia

## Educational Aims

The reader will come to appreciate that:

- Modelling COVID-19 influenced policy at all stages of the outbreak.
- Greater synthesis of epidemiological models and economic models is needed to assist policy makers.
- Models must be adapted to context, both in terms of disease behaviour and different interventions in different countries.

### ARTICLE INFO

### ABSTRACT

Models have played an important role in policy development to address the COVID-19 outbreak from its emergence in China to the current global pandemic. Early projections of international spread influenced travel restrictions and border closures. Model projections based on the virus's infectiousness demonstrated its pandemic potential, which guided the global response to and prepared countries for increases in hospitalisations and deaths. Tracking the impact of distancing and movement policies and behaviour changes has been critical in evaluating these decisions. Models have provided insights into the epidemiological differences between higher and lower income countries, as well as vulnerable population groups within countries to help design fit-for-purpose policies. Economic evaluation and policies have combined epidemic models and traditional economic models to address the economic consequences of COVID-19, which have informed policy calls for easing restrictions. Social contact and mobility models have allowed evaluation of the pathways to safely relax mobility restrictions and distancing measures. Finally, models can consider future end-game scenarios, including how suppression can be achieved and the impact of different vaccination strategies.

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## INTRODUCTION

Infectious diseases modelling in the current COVID-19 pandemic has had more attention from government and media (both social and traditional) than for any previous pandemic. This can be attributed to the huge impact of the pandemic, changes in global communication and technical advances in modelling. These advances encompass new methods, improved computational tools, public data sharing, improved code availability and better visualisation methods, which have all advanced markedly in the decade since the H1N1 influenza pandemic in 2009 [1]. Policy makers have placed greater trust in models than ever before, although models have also received considerable criticism, and their limitations need to be acknowledged.

In this paper, we describe ways in which models have influenced policy, from the early stages of the outbreak to the current date – and anticipate the future value of models in informing suppression efforts, vaccination programs and economic interventions.

## TRAVEL RESTRICTIONS

Policy on border closures followed early estimates of transnational spread of COVID-19 and was strongly influenced by mod-

elling. In January 2020, modelling based on travellers from Wuhan found that early COVID-19 case rates were significantly under-reported both in China [2] and overseas [3], and border closure policies promptly followed. China imposed an internal travel lock-down on Wuhan on 23rd January and most countries enacted limited restrictions through February and comprehensive restrictions through March; many governments using travel risk models to anticipate case numbers with and without border closures (see for example, Shearer *et al.* [4]).

Fully connected meta-population travel models have provided additional insights. Retrospective analyses have shown that the Wuhan lockdown imposed by China did little to delay the outbreak within China, but had a greater impact on other countries [5]. Models have also predicted the shifting of epicentres from Asia to Europe and from the USA to South America and Africa, based on the connectedness of these regions [6], enabling enhanced surveillance in vulnerable destination countries.

Currently, almost every country in the world has experienced local transmission, such that border restrictions are of lesser importance. However, as countries begin to move out of lockdown and seek to reignite their economies, travel modelling will again become helpful for anticipating the risk of reintroduction of cases to jurisdictions that have successfully reduced transmission.

## ESTIMATES OF THE EPIDEMIC POTENTIAL OF COVID-19

Many early models estimated a high reproduction number – the average number of secondary cases per infected case. Although precise values differed, in China prior to interventions, these mostly fell between a value of two and three [7], heralding the seriousness of the pandemic. Based on these estimates, model projections were consistent in predicting that an unmitigated epidemic would overwhelm health systems and lead to unacceptable loss of life [8–10]. A prominent example was the report by Imperial College London on the potential of COVID-19 to cause widespread infection across the UK and the US if a mitigation (reproduction number greater than one) rather than suppression (reproduction number less than one) strategy was pursued [9].

Consistent model findings of high infection rates and mortality collectively resulted in many countries grasping the seriousness of the epidemic. Consequently, public health interventions and government-imposed restrictions on human movement were initiated to reduce transmission. Models showing changes in transmission rates over time have been powerful tools for enabling policy-makers to demonstrate gains in epidemic control through public health policy and action. Many media outlets and public health officials around the world have provided explanations about the effective reproduction number and its critical threshold of one, which is the key to escaping from lockdown. Political leaders of New Zealand [11], Australia [12], the UK [13], Indonesia [14] and Germany [15] have all used this terminology in communicating decision making for easing lockdowns, demonstrating the marked increase in the public's understanding of infectious disease modelling.

## EXITING LOCKDOWN USING MIXING MODELS

As countries see their epidemic incidence curves decline in response to changes in behaviour and policy, developing a strategy to exit lockdown is vital. The aim is to do so gradually, without pushing the effective reproduction number above one and risking a second pandemic wave. Models can predict the impact of resuming different activities if the impact of each behavioural intervention is well quantified. Since most interventions were applied simultaneously, their individual contributions are unknown, and an alternative approach is required.

One approach is to examine contact patterns and thereby infer infection risk using age-specific mixing models. In 2008, age-specific contact patterns were estimated in several European countries [16], and synthetic matrices were later developed for 152 countries [17]. Changes in contact rates resulting from COVID-19 policy can be estimated using a number of sources: google mobility data provides the amount of time spent in locations (https://www.google.com/covid19/mobility/), City-mapper (http://citymapper.com/CMI) provides regularly updated data on direction requests, nation-wide behaviour surveys provide information on the impact of policies for both the number and duration of contacts in some countries. Mixing models synthesise these results to identify age-specific contact rates and use relative infectiousness and susceptibility to infer age-specific infection rates.

The findings that children are probably less likely to acquire infection and are much less likely to show symptoms when infected [16] have been incorporated into these models to assist with policy development. In particular, mixing models have shown that school closure has a modest impact on disease transmission at most, which has encouraged several jurisdictions to accelerate school re-openings, or avoid school closure [18–20].

## LOW- AND MIDDLE-INCOME COUNTRIES (LMICS)

Models designed to inform policy in low- and middle- income countries [LMICs] need to capture variation in transmissibility of COVID-19 with socio-demographic features. Models forecasting the COVID-19 epidemic in LMICs indicate that transmission is likely to be delayed by the relatively low travel numbers and the higher proportion of children in these countries [19]. This delay has given countries critical time to prepare and strengthen their often limited health infrastructure and diagnostic and surveillance capacity [21]. For example, there are only 0.23 ventilators per 100,000 of population in Uganda, compared with nine in Australia and eleven in Europe [8,22]. Despite the delay, models predict that any natural protection offered by a younger population is likely to be offset by weaker health systems, overcrowding and comorbidities [23]; hence LMICs have been advised to prepare for a "slow burn" COVID-19 epidemic.

Brazil has been one of the LMICs most severely affected by COVID-19 (thus far), and its epidemic trajectory provides some insight into the different pandemic trajectories of LMICs compared to higher income settings. The first case of COVID-19 occurred in Brazil on 25th February, 2020 and by early May there were over 100,000 reported cases and 7000 deaths, an estimated epidemic doubling rate for deaths of five days (the highest of 48 countries analysed) [24]. The rapid transmission in Brazil is attributed to a combination of inadequate policy response, high population density, close living quarters, limited access to clean water, informal employment, and transmission to indigenous populations through encounters with illegal miners and loggers in the Amazon rainforest [25].

On top of the direct COVID-19-related morbidity and mortality, indirect effects associated with disruptions to other critical medical services are anticipated. In some LMICs, health care systems will be faced with concurrent outbreaks, such as dengue in Ecuador, Brazil and other Latin American countries [26]. Models can also help estimate the indirect effects of COVID-19, such as through interruptions to the supply of antiretroviral therapy (HIV treatment) in South Africa due to COVID-19. It has been estimated that this disruption could cause a death toll on the same order of magnitude as the deaths that would be averted by physical distancing interventions for COVID-19 itself [27]. Similarly, disruptions to

vaccine delivery in LMICs could lead to major outbreaks of vaccine preventable diseases, such as measles, for many years to come [28].

Policies that have been effective in developed countries may not translate to impact in LMICs. This has been attributed to physical distancing often being impractical due to large household sizes, overcrowded settlements, and informal economies [23]. Lockdowns that severely restrict movement outside the home are less feasible and more harmful in countries where work is essential for survival.

## MODELLING THE POTENTIAL IMPACT OF VACCINATION

It seems almost certain that a vaccine will be needed if COVID-19 is to be eliminated globally. As of 2nd June, 2020, there are ten clinical trials for COVID-19 vaccines in different stages of development and 123 molecules in preclinical evaluations [29]. Modelling can be useful in evaluating the efficacy of vaccines during clinical trials and diminishing biases [30,31].

Models have already shown that an immunity of 60% is desirable to protect those who cannot or choose not to become vaccinated. However, once a vaccine becomes available, an implementation strategy will be required as supply scales up. Should we vaccinate the most vulnerable groups, those at the front-line of control or those contributing the most to transmission first? While ethical and equity considerations will appropriately drive much of this debate, modelling has a role to play. Modelling can help to assess the potential effectiveness of different vaccination strategies, such as location-specific ring-vaccination for Ebola [32], age-specific vaccination for influenza [33] and assessing long-term risks and benefits of dengue vaccination [34]. For COVID-19, strategies may differ between countries depending on the acuity of the epidemic, the age groups driving the infection or at higher risk for severe disease, and the age structure of the population.

## ECONOMIC MODELS FOR COVID-19

The containment and mitigation measures implemented by countries around the world to slow the spread and reduce mortality due to COVID-19 have resulted in a worldwide economic crisis, with the cost likely to exceed the damage from the Global Financial Crisis of 2007–2008. Unlike previous such crises, the COVID-19 pandemic has simultaneously created major downturns in both supply and demand across the world [35]. This creates significant policy challenges for governments to design strategies that take into account both the effectiveness of public health intervention measures and their negative socioeconomic consequences [36].

Containment and mitigation efforts, which are aimed at saving lives, avoiding human capital losses and flattening the epidemic curve, also reduce economic activity [37,38]. This intentional reduction of economic transactions has been undertaken by many governments as a necessary public health measure, at least in the early stages of the epidemic. Apart from the humanitarian perspective, there are economic benefits to counter some of the losses of these policies, such as avoiding loss in income due to premature deaths, workplace absenteeism, and reduction in productivity. Contractions in supply and demand also come from physical distancing, travel restrictions, non-essential business closures and other measures, as people work and consume less [39].

Some studies have used early estimates of infection rates and case fatality ratios to assess healthcare costs due to the pandemic and provide cost-benefit analysis of non-pharmaceutical interventions [40]. Others have used simulations to model epidemiological scenarios in inter-temporal general equilibrium models [41]. For example, a dynamic stochastic general equilibrium model is used to model global economic outcomes under different scenarios of the pandemic's evolution over the remainder of this year [42]. A limitation of this modelling approach is that it requires a large number of inputs and assumptions on economic relationships and epidemiological characteristics. As economic consequences from the COVID-19 pandemic originated from epidemiological factors and these factors will continue to play a role in the dynamics of control, the economic trade-offs between public health and economics should be considered and analyses that combine epidemiological and economic modelling will be valuable.

## CHALLENGES IN DEVELOPING MODELLING FOR POLICY

Much of the value of models in the COVID-19 pandemic is in informing immediate policy decisions. A collaborative relationship between modellers and policy-makers ensures that models focus on priority questions. Providing modellers with a clear view of the policy environment allows them to propose and develop models that support decision making. This may go beyond policy-makers outlining the policy questions of interest and the interventions under consideration, and should ideally create an environment where modellers and policy makers work in partnership.

Modelling analyses may also play a role in broadening the scope of options under consideration. For example, modellers advising the UK health authorities did not initially explore a strategy that involved increased testing because they had been advised that there were limits on the extent to which testing capacity could be scaled up [43]. However, modelling more ambitious scenarios can provide high benefits at low cost, even if the strategies simulated are not immediately able to be enacted – if models had shown that increasing testing, tracing, and isolation would result in dramatically better outcomes, these activities may have been prioritised sooner in the UK [44]. Similarly in Australia, models presented to the Australian Government in March 2020 examined only mitigation strategies [45]. Had these early models shown the enormous impact potential for suppression, earlier and shorter lockdowns may have been planned.

The current pandemic crisis has led to a resurgence of interest in modelling, and an increase in its use for guiding policy. Modelling advice should always be developed and considered in context, allowing for setting-specific limitations in capacity. Early analyses have been biased towards high-income settings where both modelling expertise and reported cases have been concentrated. However, as the pandemic now shifts towards highly-vulnerable LMICs, a concerted effort is required to provide international modelling support to local containment efforts.

## DIRECTIONS FOR FUTURE RESEARCH

Models will continue to be relevant in future for assessing:

- strategies for exiting lockdown.
- vaccination scale up decisions.
- opening international travel

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