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Undoing elimination: Modelling Australia's way out of the COVID-19 pandemic

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ABSTRACT

In the middle of 2020, with its borders tightly closed to the rest of the world, Australia almost achieved the local elimination of COVID-19 and subsequently maintained 'COVID-zero' in most parts of the country for the following year. Australia has since faced the relatively unique challenge of deliberately 'undoing' these achievements by progressively easing restrictions and reopening. Exploring the role of mathematical modelling in navigating a course through the pandemic through qualitative interviews with modellers and others working closely with modelling, we argue that each of these two significant phases of Australia's COVID-19 experience can be understood as distinct forms of 'model society'. This refers at once to the society enacted through the governance of risk, and to the visions of societal outcomes – whether to be sought or to be avoided – that are offered up by models. Each of the two model societies came about through a reflexive engagement with risk facilitated by models, and the iterative relationship between the representations of society enacted within models and the possibilities that these representations generate in the material world beyond them.

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Introduction

On 9 June 2020, as the COVID-19 pandemic developed around the world, Australia recorded no locally acquired cases (ABC, 2020, June 9; Packham, 2020). This had not been anticipated, nor had it been the objective of the national response strategy. This moment, in which local elimination of the SARS-CoV-2 virus appeared to have inadvertently come within reach, has fundamentally shaped the nation's experience of the pandemic since. The subsequent pursuit of 'COVID-zero' saw it successfully achieved and maintained in some states and territories through stringent international and internal border control, while others struggled with outbreaks associated with returning international travellers. This, however, left Australia facing the unusual challenge of 'undoing' elimination. In considerations of how to wind back the self-isolation of some parts of the country from others, and of the nation from the rest of the world, mathematical modellers were tasked with identifying the vaccination targets that trigger the progressive easing of restrictions and reopening of the country. They were, in other words, working to identify the conditions in which COVID-19 can effectively be 'let in'.

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This paper explores the role of mathematical modelling in navigating the path that took Australia, first, to the verge of local elimination and, later, away from it. In the case of COVID-19 and other novel virus outbreaks, early and rigorous control of transmission can play an important role in 'buying time' to better understand the virus and prepare healthcare systems for increased transmission (Wu et al., 2021). However, this relatively unique case in which the *undoing* of elimination ultimately became a policy objective supported by modelling unsettles the promissory discourse of public health approaches employed to address some infectious diseases that take the elimination of disease as the end goal and modelling as a tool to help achieve this (Rhodes & Lancaster, 2021a, 2021b). This orientation towards elimination belongs to a governing framework that includes and makes possible global strategies to 'end' viral infections, such as HIV, viral hepatitis and sexually transmitted infections, by 2030 (WHO, 2022) as part of a broader goal of controlling, eliminating or eradicating a number of diseases within the United Nations 2030 Agenda for Sustainable Development (UN, 2015). Viral elimination strategies have governing effects, including for how disease is made visible as an object which can be contained and controlled, and constituted as a problem requiring urgent policy action (Lancaster et al., 2020b). The success of such initiatives is seen to hinge on 'ongoing and deliberate efforts' underpinned by 'a defined, evidence-based, technical strategy' (Whittaker et al., 2014), with mathematical modelling widely employed as one key form of evidence.

Mathematical models are one means, arguably a prime means in the time of pandemic, through which societies are governed, and through which we can therefore understand how the governance of societies takes place. In this paper we analyse the emergence and achievement of SARS-CoV-2 elimination, and its undoing and abandonment, in Australia as two distinct configurations of 'model society' (Rhodes et al., 2020). We refer to model society in two ways: first, as a configuration of society which is enacted in relation to the governance of risk and uncertainty through the use of models, mathematical and otherwise; and second, as a normalised or idealised representation of a societal outcome that is offered up by models, whether to be sought or avoided.[1] A model society is thus at once governed in relation to risk through modelling and also has governing effects through its anticipation of futures in relation to populations, states, nations and their possibilities (Rhodes et al., 2020; Sandset & Villadsen, 2022). Importantly, we see model societies as *configurations*, and by this we mean that a model society is always a construction, always an enactment, always in-the-making, with performative and material effects (Anderson, 2021; Rhodes & Lancaster, 2019). By drawing on analysis of the published academic literature, media articles and interviews with COVID-19 modellers and others working with models, we show how mathematical models shaped the objectives and outcomes of key aspects of Australia's response in the first two years of the pandemic.

Background

Along with others in the Asia-Pacific region including Taiwan, Singapore and New Zealand, Australia was among a small number of countries to pursue an approach, whether explicitly or not, that came to be known as 'COVID-zero' (Power, 2021; The Economist, 2021). COVID-zero was achieved in Australia, as in many of these countries, through border closures, mandatory 14-day border quarantine, extensive testing and contact tracing regimes, stringently policed stay-at-home orders and curfews, and other measures. Australia's policies of restricted international travel left many thousands of Australian citizens and residents 'stranded' overseas and those within the country unable to leave without a permit (Gretener, 2020; Taylor, 2021, January 9). With the availability of vaccines and the challenges of the Delta and subsequent variants, however, the COVID-zero approach has been abandoned.

These measures were enacted by the federal government or by the governments of the eight states and territories of Australia, with the federal government controlling national borders and administering quarantine, and the states and territories controlling domestic borders and

administering health care and public health measures. In addition to the public health capacity within each of these jurisdictions, public health advice was shared with policy-makers through the Australian Health Protection Principal Committee, which is comprised of invited experts as well as the Australian Chief Medical Officer and state and territory Chief Health Officers (Australian Government Department of Health and Aged Care, n.d. a).

Supporting the advice to decision-makers throughout the pandemic, among other forms of expertise, was extensive mathematical analysis and modelling of COVID-19 transmission and interventions conducted in state and territory health departments, by groups based in universities, and by private providers. In contrast to the transparency of the work of government advisory bodies in some other nations, such as the Scientific Pandemic Influenza Group on Modelling (SPI-M) and the Scientific Advisory Group for Emergencies in the UK (Evans, 2022; Medley, 2022), relatively few details of the advice informing government decisions in Australia have been made publicly available.

Theoretical framework

Our analysis focuses on how modelled projections play a role in evidencing elimination by shaping actions in the present in light of the futures they project, thus delimiting what becomes possible for policy and intervention (Lancaster & Rhodes, 2022; Rhodes & Lancaster, 2021a, 2021b). This is the case, for example, in global efforts to eliminate hepatitis C in which models have materialised hepatitis C treatment promise in the 'new era' of Direct-Acting Antiviral treatments for hepatitis C. The development of models theorising 'treatment-as-prevention' is regarded as a foundational moment in the governance of hepatitis C, and subsequently HIV, and continues to drive intervention and policy through elimination targets (Rhodes & Lancaster, 2021b; Sandset, 2021). In the governance of health and disease elimination, modelled projections evidence-make elimination potential, at the same time as taming risk and uncertainty, thus closing down unknowns into a governable present (Adams et al., 2009; Hacking, 1990; Rhodes & Lancaster, 2021a). By enumerating futures without disease, models help constitute 'elimination states' (Rhodes & Lancaster, 2021a), acting as technologies of governance which enact populations and states, enabling accountability and action.

The idea of societies being governed through risk is well established. This is, for instance, a core narrative of risk factor epidemiology in public health, and of late-modern shifts towards the anticipation of disease and danger through the invention, surveillance and science of 'risk' (Armstrong, 1995; Castel, 1991; Hacking, 1990). Enumerated projections produced through mathematical models extend this logic of risk and anticipatory governance (Adams et al., 2009), enabling a means to evidence-make futures in the face of immediate epidemiological and other unknowns. Seen as a form of risk governance, there are parallels, then, between the 'model society' and sociologist Ulrich Beck's concept of 'risk society' (1992). With this concept, Beck offered an influential account of how modernisation has produced a world permeated by risks and uncertainties which are difficult to trace or predict, with an accompanying reflexivity generating *the concept, and the sciences, of risk* as a (faltering) means to respond to these challenges produced by modernisation itself. Mathematical modelling is one such response in a time of pandemic – a reflexive 'evidence-based' effort to tame risk and uncertainty which entangles in the evolving uncertainty and pandemic it seeks to navigate. In this paper, we trace configurations of model society in relation to the anticipation of COVID-19 in Australia, emphasising this as a reflexive practice of science and society in-the-making.

As Beck reminds us, statements of risk in models or other forms are not simply statements of evidence or fact, but also contain a normative dimension as part of their constitution (Beck, 1992, p. 27). This accentuates model societies as forms of governmentality, as *imaginations* of delimited future which impact *materially* in the present (Dean, 1999). Science and technology studies (STS) scholars have taken thinking in relation to risk governance further to explore how the management of risk and uncertainty through mathematical modelling and other calculative

practices *makes* society, through a process whereby numerical statements and their worlds co-evolve and mutually constitute one another (Callon, 2006; Castel 1991; Hacking, 1990; Rhodes & Lancaster, 2021a; Sismondo, 1999). Understanding modelling as a form of *evidence-making intervention*, we see evidence and policy interventions not as distinct, definite and stable, one translating neatly into the other, but rather as emerging together through relations and practices which they, in turn, work to reshape (Rhodes & Lancaster, 2019, 2021a). Models thus both come into being, and have effects in the world, through assemblages of social relations, policy-making institutions, worldviews, computing technologies and other objects and practices (Rhodes & Lancaster, 2021a). This perspective offers a way of understanding how mathematical models have taken a central part in adaptive evidence-making responses to COVID-19, enacting *evidence enough* in conditions of limited understanding of a new virus (Lancaster et al., 2020a). Models have thus played key roles in defining and realising material effects and outcomes in society (Anderson, 2021; Evans, 2022; Lancaster et al., 2020b; Rhodes & Lancaster, 2022a, 2022b) – including in ways that 'might refute, or even happen independently of, what humans believe or think' (Callon, 2006, p. 17) and may produce what John Law has termed 'collateral realities' (2011). In this paper, then, we treat the mathematical model not merely as a technology which seeks to 'evidence' a model society – a society acceptably governed by risk – but as a technology which 'makes' society through its performance of imagined futures (Rhodes & Lancaster, 2021a, 2021b).

Methods

Our analysis is based primarily on interviews with 23 participants engaged in or working closely with COVID-19 modelling in Australia, with a variety of training and professional backgrounds, including in epidemiology, mathematics, physics and computer science. These interviews were conducted between August 2021 and May 2022, and included a series of follow-up interviews with four participants. Interviews were carried out online via Zoom by SA and were approximately one hour in duration. The interviews were semi-structured in format and explored various themes, including key moments and shifts in Australia's pandemic response; applications of different types of mathematical modelling to support policy interventions; the communication of modelling evidence to policy-makers and the public; and the challenges and implications of working with limited data and inherent uncertainty. All interviews were undertaken with consent, audio-recorded and transcribed verbatim. Ethics approval was granted by the University of New South Wales Human Research Ethics Advisory Panel (HC210221). Excerpts from the transcripts are presented throughout the article with the interview participant number in square parentheses; in order to avoid identifiability no biographical information is included.

The conduct and analysis of interviews was situated in relation to a critical reading and review of relevant media and published academic articles, which we used to help trace how modelling was being applied, including in light of changing pandemic, data availability and policy circumstances. The account presented here was developed through analysis of the interviews, media and published academic literature, focussing on the ways that *what it was possible to know through models* shaped *what it was possible to achieve through policy.* Our analytical approach does not seek to establish a 'true' account of Australia's modelling and its influence on policy, but rather to explore how different practices and ways of thinking open up possibilities for policy response, and we take the interview, media and published academic accounts themselves as performing such possibilities. The analysis focuses, albeit not exclusively, on the work of a group of modellers led by the Peter Doherty Institute for Infection and Immunity, hereafter referred to as the Doherty Institute (Doherty Institute, n.d.), which featured in the advice of the Australian Health Protection Principal Committee and was employed in the development of the federal government's 'reopening plan' in the latter half of 2021. This account consists of two phases, presented in turn below, in which distinct 'COVID-zero' and 'transmission-reducing' enactments of 'model society' emerged in Australia.

Achieving elimination

The first decision

In 2020, early COVID-19 modelling in Australia conducted by a team associated with the Doherty Institute explored scenarios of unmitigated importation and transmission of the SARS-CoV-2 virus and showed a society and a healthcare system overwhelmed by cases (Moss et al., 2020). This modelling was called upon to support 'the first decision', which was 'do we do nothing or something?' [2], by depicting a worst-case scenario in the absence of a public health response. Based on estimates of the basic reproduction number from Wuhan, China, and with no evidence about how the virus might spread in Australia, these projections of rising case numbers were 'simple maths' – indeed, 'barely even a model' [11], in the words of one modeller. These projections were, nevertheless, *evidence enough* (Lancaster et al., 2020a) at that moment in time, enabling action in an uncertain and evolving situation of need: it was said that 'we knew we had to do something' [2]. A model society was being enacted – that is, an approach to the governance of society in which risks are considered, grasped, quantified, taken seriously and taken up as matters of concern *through models*. The modelled imagination of worst-case projections and scenarios performs a narrative of pandemics potentially 'big' and/or 'catastrophic' (Lakoff, 2017; Rhodes & Lancaster, 2022a), a configuration of society which tames future uncertainty through enabling pre-emptive action in-the-now, even if such action is not without controversy and perhaps even unprecedented.

This early modelling was seen to generate an authority to act within the policy-making assemblage forming through these efforts. The modellers interviewed recounted that 'policymakers had never seen this kind of stuff before and so were really looking to experts' [6]. Unlike in some other countries where decision-makers were slower to act to implement interventions (Evans, 2022; Rhodes & Lancaster, 2022a), policy-makers were perceived to be 'listening to' public health advisors [19, 22] and were 'driven by the advice that they've been getting' [6] that action was required. The response by authorities was 'very quick and very significant' [11]. The Australian government restricted travel from China and required citizens and residents returning from China to self-quarantine on 1 February 2020, and extended the travel restriction to all other countries and instituted mandatory quarantine for all returning citizens and residents throughout March. By the end of March, non-pharmaceutical public health measures had been implemented by state and territory governments across the country requiring people to stay at home except for essential activities and limiting public gatherings to two people.

These stay-at-home orders – and what would later be referred to as 'lockdown' – had not been included in previous pandemic influenza preparedness planning, having been considered socially and politically unviable. However, the strict public health interventions imposed in Wuhan were observed to be effective in containing the transmission of COVID-19, and stay-at-home orders were attempted in Australia. Testing, tracing, isolation and quarantine (TTIQ) of cases and contacts emerged as a means of containment more relevant and 'feasible' for COVID-19 than it is for influenza, as the onset of the infectious and symptomatic periods is delayed in the former relative to the latter [22]. TTIQ would become crucial mechanisms for the constant assessment and management of risk throughout the pandemic. As was suggested in modelling such as that reported by Moss et al. (2020), TTIQ and physical distancing had the potential to significantly reduce transmission compared to a scenario of unmitigated transmission, in which 'the COVID-19 epidemic would dramatically exceed the capacity of the Australian health system' (p. 5). While the policy settings put in place 'were well-informed by public health and epidemiological principles' [12] and, as some have argued, did not strictly require the support of mathematical models, these projections played a key role in orientating policy-makers towards and marking out a horizon of policy-making. The making of pandemics 'big' or 'catastrophic' is a spur to such action (Rhodes & Lancaster, 2022a).

In illustrating a catastrophic outcome to be avoided and the difference that might be made by the kinds of public health measures put in place in February and March 2020, these early models enacted COVID-19 as a matter of concern and those public health measures as the interventions to address it. In their situation, models have been made as evidence for such a response – taken to justify and validate the effectiveness of the measures employed. For example, the Chief Medical Officer for the Australian government, Brendan Murphy, stated in an April 2020 press conference (ABC, 2020, April 7) that, 'The most important message from these models is that we know that the tools we are using […] do work, and we can scale them up and down as necessary, and the data we have so far suggests that *they are working*'. A modeller recalls that it became 'clear that this has worked and [transmission is] probably flattening out or coming down' [20]. It appeared that the catastrophe projected in the initial modelling was being averted.

The rationale for the initial government response was said to be 'buying time', pausing or at least slowing down the entry of COVID-19 into Australia, in order to better understand the virus and to prepare to manage its spread until a vaccine or cure became available (Price et al., 2020). The approach was dubbed 'aggressive suppression'. Following some debate in policy circles and the media, the federal government resisted calls from some quarters to explicitly pursue the elimination of the virus. It was maintained that, while suppressing the virus 'to the point of eradication […] would be a magnificent outcome', in the words of then Deputy Chief Medical Officer Nick Coatsworth, local elimination of COVID-19 while it continued to spread overseas would be at once too hard won and, if achieved, precarious, inevitably short-lived and could foster a sense of complacency (Scott et al., 2020).

By early June 2020, however, Australia had zero locally acquired cases, in a sense having bypassed any agreement or formal strategy on elimination to inadvertently achieve it [3]. Modellers themselves describe being 'all pleasantly surprised that we achieved this elimination that wasn't really anticipated' [19], for 'we'd committed to this non-elimination strategy but then it kind of happened' [6]. This was seen to be because the interventions put in place by federal and state and territory governments had proven more effective than expected: 'the big surprise was, "Whoa! Actually, lockdowns really do work in Australia"' [23]. This was the unexpected achievement of the 'model society' that had been enacted as Australian governments took action in anticipation of the possible catastrophic outcomes projected by models. No single Australian model had explored, let alone was employed to promote, the elimination of the SARS-CoV-2 virus as a public health objective. And yet the 'collateral reality' (Law, 2011) produced as various policy levers were pulled at different levels was an emergent effect partially contingent on the evidence-making authority of models.

As one informant commented, 'if that had been the end of it, you know, it would have been a real success story' [7] – for, while not the objective at the outset, the control of the virus to the extent that it could be said to have been eliminated had come to be the measure of success of government response to COVID-19 pandemic. That was not, however, the end of it: 'That then set us on an interesting trajectory, really, that was quite different from others' [19]. The unanticipated local outcomes in these first months of the pandemic in Australia would lead to new directions in the modelling of local transmission and shape subsequent government response, as a COVID-zero model society came to be realised.

Maintaining COVID-zero

After the initial national border closures in March 2020 prevented most travel into and out of the country, and case numbers had subsequently declined, modelling efforts were redirected towards understanding and managing the possibility of a quarantine breach and the implications of such an incursion. The ongoing suppression of the virus was considered viable and 'turned into the sort of operational strategy' once effective suppression had been demonstrated to be possible [1]. In the words of one senior modeller, 'We had to develop new methods to say, 'How likely is it

to come back? How likely is it to get through the quarantine system? And how are we going to be […] prepared for that inevitable leak and respond to it?' [12]. The challenge was seen to be to find ways to assess and contain the risks associated with such a 'leak'. In this sense, the unexpected success of Australia's initial response in eliminating COVID-19 was prompting efforts that would effectively maintain this status – and consolidate the 'model society' that was emerging.

In contrast to the 'assumption-based modelling' [20] of the initial response described above, these efforts centred on processing data gathered from local society to undertake assessment of the current situation, 'nowcasting' and forecasting of the transmission of COVID-19. These activities were carried out by various groups, both private and based in universities, at federal and state/territory levels around the country. New information was constantly becoming available in this 'incredibly data-rich' context [20], allowing the modellers to 'get the computers churning for […] a few hours again, and […] see how that [new input] changes things' [22]. Modelling thus tracked the interacting elements of rapidly changing situations – 'as COVID spreads, behaviours change, public health responses change, lockdowns happen, borders close' [11] – in 'an iterative, adaptive process' [12]. A challenge in this, however, was that 'the information you get is always a little bit out of date and a little bit incomplete' (19), leaving models always 'catching up' with what is happening in society.

Modellers 'adapted and developed our models' to include the non-pharmaceutical interventions, including TTIQ and physical distancing, in place in Australia, which 'shifted […] the role of modelling to also supporting measurement of how effective those systems were' [12]. Modelling could thereby be put to use to validate these interventions and point to where they could be strengthened, as nowcasting and forecasting made it possible to see that 'we need to do just slightly different things' [5]. As the models 'account[ed] for that extra level of stringency [associated with the public health measures in place] and the suppression it caused', they therefore started to support 'the strong, essentially, elimination strategy that [those public health measures] capture' [12]. The models were at once shaped by, and shaping, society.

Among the new mathematical and statistical tools developed was the concept of *transmission potential*, which 'bec[a]me central to Australia's planning' [12] and to a revisioning of this model society. Developed by modellers associated with the Doherty Institute to accommodate the unexpected success of the public health measures in suppressing the transmission of COVID-19, transmission potential enabled quantification of how the SARS-CoV-2 virus *would* be spreading within a population at any given time – based on real-time behavioural data about people's mobility and physical distancing practices in the context of the public health orders in place – *even while the virus is absent* from the community. It is equivalent to the effective reproduction number, or the rate of transmission in a population with public health measures applied, but can be calculated in lieu of the latter during periods of low or zero transmission of the virus (Anderson & May, 1991). The transmission potential concept effectively enabled the performance of the TTIQ system, the level of physical distancing requirements and the behaviour of the Australian population to be *immediately and constantly assessed* against a level of risk considered acceptable, with 1 the threshold at which an outbreak may grow rather than decline, as it is for the effective reproduction number.

Transmission potential was calculated for each state and territory and presented to peak national decision-making committees from early May 2020, and later to the public in weekly 'Common Operating Picture' infographics (Australian Government Department of Health and Aged Care, n.d. b). With a quantification of the level of risk in the current community context to hand at all times, federal, state and territory governments were guided in the implementation and adjustment of non-pharmaceutical interventions, including those enacted in response to quarantine breaches. During and after outbreaks, analysis of the difference between the population-average transmission potential and the effective reproduction number estimated for a cluster of actual cases enables learning about the dynamics of the cluster and the effectiveness of the response – with a lower reproduction number compared to the broader potential for transmission taken to indicate a strong response

to contain the outbreak, for example (Golding et al., 2021b). Through the collation and analysis of data from different outbreaks around the country over time, 'you start to build a picture of how much contact tends to be reduced when these measures are in place', one modeller involved said [14]. Among other applications, the transmission potential concept was also incorporated into forecasting to estimate the potential for widespread transmission once an outbreak extended beyond a localised cluster of cases (Moss et al., 2022), and used in the exploration of different physical distancing scenarios – enabling comparison of the effect of easing restrictions at different times on transmission potential, for example (Golding et al., 2020a, 2020b).

By *imagining* the spread of the virus when it was not present in the community in order to better contain it should it appear, the modelling of transmission potential helped to facilitate the realisation of COVID-zero over the course of the next year. Transmission potential modelling worked to evidence-make COVID-19 as an absent presence – that is, as something to be continually managed, even in the absence of community transmission – as well as to materialise COVID-zero within the Australian community, even while the virus periodically permeated the nation's borders. It can be understood as a reflexive response to the unexpected achievement of local elimination, one that subsequently and iteratively worked to maintain elimination by bringing about an acceptable level of transmission potential within society. This approach marked a departure from the logic of the initial catastrophe modelling, employed in situations of irreducible uncertainty to prevent the modelled society from being realised. As public health measures were refined, assessed, and evidenced as effective, COVID-zero was consolidated as the goal to which the policy-making assemblage was oriented. While other forms of data analysis and modelling also contributed to achieving and maintaining COVID-zero, calculations of transmission potential are said to have provided a crucial justification for the significant interventions being instituted by governments, conferring upon them an authority to introduce significant and unprecedented measures with disruptive effects on social and economic life in the name of curbing the *potential* of a virus to spread. In the words of one modeller, 'you need to be able to tell people why those policies are in place' [1].

This authority was grounded in a performance of numerical precision, with the difference between increasing or waning transmission a matter of decimal places in estimates of transmission potential or the effective reproduction number. Indeed, the role of the statistical analysis and mathematical modelling conducted in this period was premised on the reliable identification and management of cases made possible by an effective TTIQ system. A pillar of COVID-zero, case counts were at once obtainable and meaningful only while numbers of cases were relatively low, and seen to be essential in keeping numbers of cases low. Case counts were communicated to the public via press conferences by state premiers and their Chief Health Officers, which were held daily and widely reported in many jurisdictions, including via daily live-to-air press conferences, for significant periods in 2020 and 2021. By encouraging the public's compliance with physical distancing requirements and presentation for testing, these case counts contributed to the making and reproduction of COVID-zero and thereby to the realisation of a 'model society' in the sense of a picture of success.

COVID-zero was thereby enacted throughout the latter half of 2020 and the first half of 2021 through constant adjustment of public health measures, at least in part informed by and materialised in the evidence-making practices of mathematical analysis and modelling. Replacing earlier doubts that lockdown could be effective in containing transmission was a 'lock down hard and lock down early' approach [1]. Periodic city or state-wide lockdowns became accepted response to quarantine breaches around the country, perpetuated by their success in returning to COVID-zero [3]. They thus emerged as a 'creature of COVID-zero' [3], producing an 'epidemic of circuit-breakers' [2]. While these lockdowns were typically promised by leaders to be 'short' and 'sharp', some became among the strictest and longest lockdowns anywhere in the world in the first two years of the COVID-19 pandemic – most notably those in the city of Melbourne from July to October 2020 and August to October 2021 (Boaz, 2021). Those states and territories that experienced incursions in this period were compelled to return to COVID-zero while a vaccine

remained unavailable and internal borders were closed to them in order to preserve the COVID-zero status of the other states and territories [17]. By the time of the outbreak of the Delta variant in mid-2021, COVID-zero had become accepted not merely as the implicit logic but as an explicit policy goal (Malone, 2021). These processes by which COVID-zero was actualised might be described as 'performative nominalism', whereby 'articulations of a neologism […] participate in producing the referent of the new term' (Pickersgill, 2019).

COVID-zero thus emerged as the answer to a question that had arguably never been properly posed – for there had not been a public conversation about 'where do we want to get to as a society?' [6] or 'where are we going with this?' [5], as some participants expressed that there ought to have been (see also e.g. Grattan, 2020). It was a product of actions taken in part on the basis of models of, first, the catastrophic outcomes of unmitigated transmission and, later, monitoring of the effectiveness of containment measures, even in the absence of local transmission. With the unexpected success of the former paving the way for the latter, this outcome reflects the iterative relationship between the representations of society captured within models and the possibilities that these representations generate in the material world beyond them. The near-elimination of COVID-19 had not been the intention of policy-makers: it was not the 'stated goal' to 'maintain COVID-Zero until we've got vaccination' [23]. Instead, it came about incrementally as developments in society were fed back into models, further informing perceptions and ambitions and, in turn, adjustments to policy. The subsequent effects reveal an agency on the part of models and their policy-making assemblages that exceeds that of their human actors alone. As we discuss in the following sections, the achievements of this initial, COVID-zero model society then shaped the possibilities available later.

Undoing elimination

A 'genuine dilemma'

As the NSW outbreak of the Delta variant defied efforts to contain it and spread into multiple states on the east coast in mid-2021, Australia experienced the 'interesting mix' of 'having COVID and no COVID' in different parts of the country [17]. Where the first phase of the pandemic might be said to have been characterised by a relative unity of decision-making across the country, it is said that there was at this point 'increasing fragmentation, nationally, of the way the response was organised' [19]. The rollout of the vaccine – promised by the government to allow Australia to reopen to the rest of the world – had commenced but experienced significant delays, attracting recrimination around the federal government's sourcing and distribution of vaccines (Sullivan, 2021; Tomazin & Lucas, 2021). The enacted COVID-zero model society was coming under increasing pressure as more voices questioned whether COVID-zero remained viable or desirable. Some informants perceived that this manifested as an attitude of 'models versus us' [10] within this increasingly 'fractious' public discourse [11].

With a deepening sense of the costs of COVID-zero, the country was grappling with what successful management of outbreaks of COVID-19 in the community looked like. The imperative of minimising the damaging effects of border closures and lockdowns on mental health, economic, educational and other aspects of social life increasingly vied with that of minimising case counts. Of the mounting tension between the two, media commentator Waleed Aly wrote:

> 'We must surely acknowledge something the rest of the world has known for at least a year. This is a pandemic, and pandemics bring inescapable pain. They create a world in which there are only bad choices available. We don't seem to accept this in Australia. We seem to expect close to zero death at little cost. And the mere notion that this is possible when it has eluded everyone else – this Australian exceptionalism – is the chief contradiction behind our angst' (2021).

In June 2021, the World Health Organisation's Dr Mike Ryan commented that Australia and other countries in a similar position faced a 'genuine dilemma' in deciding to open up again and

experience the probable re-importation of the virus, effectively undoing the elimination achieved in the first phase of Australia's pandemic response (Bourke, 2021). The latter was performed as *inevitable* by some, but this did not achieve uniform or unconditional acceptance. As remarked by one modeller at the time, 'the right thing to do now isn't obvious, where I think it was last year [in 2020]' [7].

A strategy to make the reopening of the country conditional on the achievement of high rates of vaccination was devised as the solution to this dilemma, and underpinning this strategy was mathematical modelling. Modelling was *undoing elimination* through its evidence-making as it was put to use to determine the best approach to the allocation of vaccination among different ages and groups within the population, as well as the vaccination targets that would trigger each step of the federal government's four-phase plan to ease restrictions and reopen the national borders. The objectives of the strategy to enable the transition between the phases it stipulated were the 'minimisation of moderate and severe health outcomes' and 'reduction of the intensity and length of application of socially and economically disruptive public health and social measures, which are currently the primary means of reducing transmission' (Doherty Institute, 2021a, p. 4). This was described as 'a whole different framing of the problem space' that required 'working out your risks and benefits within that wider framing' [19]. Models were thus the means by which risks were being reflexively reengaged and redefined. Model society was in turn being remade in terms of an explicit balance of competing imperatives – a balance understood to be identifiable only through modelling.

'Learning to live with' the virus

The modelling for the 'national plan' initially simulated a single national epidemic starting with just 30 cases, to explore different vaccine targets and the effect of vaccination on the transition to the second phase of the national plan. The transmission potential parameter was employed once again, with a transmission potential estimate of 3.6 for the Delta variant based on averaged observations from NSW in March 2021, which was a period with few social restrictions and no significant outbreaks (Doherty Institute, 2021a, p. 7). This allowed comparison of the transmission potential in different age groups for different allocation strategies[2], taking into account different vaccine dosing intervals, at differing levels of vaccine coverage (50, 60, 70 and 80 per cent) of the eligible population aged 16 and over. This modelling also explored the level of public health interventions – ranging from the baseline as seen in NSW in March 2021, through low and medium settings, to high levels of restrictions, as seen in Victoria in August 2020 – required to bring the transmission potential to below 1 in different vaccination coverage scenarios. The combined effects of vaccination and public health measures on transmission potential at different levels of vaccination coverage were calculated. Further analyses investigated the transmission dynamics and health impacts following transition to the second phase at different times. On the basis of this modelling, a 'transmission-reducing' strategy was devised, based on the identification of the 'all adults' allocation strategy as resulting in 'greatest reductions in harms across all age groups, regardless of vaccination status. (Doherty Institute, 2021a).

The modelling supporting the national plan was becoming more complex, for 'now we have these almost impossible sets of interactions between different vaccines and also different variants of the disease […] the level of vaccination and the mix of vaccination, and waning vaccine efficacy, and different variants that have different resistance to vaccines' – all of which makes it 'a much harder thing to model' [7]. One modeller reflected that 'It was imperfect, you know. Delta was relatively new. Most of the evidence was from previous strains. We were extrapolating and bridging as well as we could' [19]. Nevertheless it was once again made as *evidence enough* at the time, in its situation. Even if the modellers involved were acknowledging its imperfectness by the ideal standards of 'evidence-based intervention', the modelling was acquiring considerable power in the governance of COVID-19, setting out the framework for the 'transmission-reducing'

model society that was emerging. It was described as having 'taken on *a life of its own*, and it's almost like this political symbol now' [3].

In setting out the complex and interacting factors affecting the safe reopening of the nation, the scenarios explored in the modelling led by the Doherty Institute are described as 'clearly (and deliberately) artificial and serve to inform high level policy strategy' (Doherty Institute, 2021b). The report in which the modelling is presented goes on to state that 'in reality, the national COVID-19 epidemic has been and will continue to be a "fire" fought on multiple fronts' (Doherty Institute, 2021b, p. 2). This model society is considered to be characterised, then, by a 'whole-of-society response' [19] that included both high-level strategy and local, differentiated implementation occurring at multiple sites. Data analysis and modelling would support the 'bridging' of these levels, including by the ongoing assessment of the transmission potential and analysis of the effectiveness of interventions that had previously been established as crucial, as discussed above. This analysis would further penetrate the local level with 'real world evaluation of impact of social measures at small area level' (Doherty Institute, 2021b, p. 17). This situational assessment was expected to allow benchmarking against the hypothetical scenarios explored in the national plan modelling 'to guide real time policy decision making' (Doherty Institute, 2021a, p. 2). By facilitating the 'use [of] that knowledge [about the effectiveness of interventions] to make sure that you refocus your public-health responses' [19], the national plan was thus envisaged as an explicit framework for the reflexive management of risk at more local levels.

At the same time that analysis was undertaken to better understand and monitor the dynamics of transmission at local levels, the high-level framework of the national plan abstracts from local situations to redefine success not in terms of absolute numbers of cases, or the presence or absence of the virus in the community, but rather the relative rates of protection conferred by vaccination. It is suggested by some that this shift enables greater attention to the dynamics of transmission – 'the underlying issues […] how effectively we're responding to it' – which had been obscured by a disproportionate focus on the case numbers [16]. 'Moving away from looking at zero cases and looking towards who's in ICU, can the health system cope, how many people are vaccinated' [4] represents a shift in the objectives and modes of governance supported by different numbering practices in the 'transmission-reducing' model society. The modelling of proportions of the population vaccinated that is the centrepiece of the national plan is a measure of 'how effectively we're responding to it' that *does not depend on precise knowledge of the extent of COVID-19 transmission* – and which enacts COVID-19 as nevertheless governable (Rhodes & Lancaster, 2021a). It works to confer a sense of protection in the absence of knowledge of specific cases, reflecting a new way of governing the risk of COVID-19 during the reopening of the nation.

This shift from the absolute to the relative changed the sense of the harm associated with COVID-19 and of what it meant to be protected from such harm. Vaccination was said to offer a protection from such harm that is tantamount to 'avoiding' the pandemic: 'Get [the vaccination rate] up to 80, 90 per cent and then you can open up, and you've pretty much *avoided the pandemic*, which is an incredible achievement' [4]. The notion of the protection conferred at the population level by vaccination met with some controversy, however, with respect to who was or was not included among those rates of vaccination. The population eligible for vaccination included only those aged 16 and above, meaning that children were initially excluded from the direct benefit of the vaccine (Martiniuk, 2021). The target vaccination rates of 70, 80 or 90 per cent then did not correspond to the actual proportion of the total population with the transmission-reducing immunity offered by the vaccine, arguably performing a greater sense of safety than they actually represented (Tsirtsakis, 2021). Proposing to open at a vaccination rate of 70% was viewed with concern by some as a proposal that vaccinating 'one in two in the general community was safe' [8].

Such a shift in the way models constituted COVID-19 as an object of control in its social worlds has been attended by a different mode of managing and reporting cases. The once daily announcements of case counts by many state premiers and their chief health officers at press conferences ceased – although not without some outcry from a public accustomed to the daily briefing (Patrick,

2021). The objective of TTIQ shifted from 'zero tolerance' containment to an acceptance of some number of cases (Doherty Institute, 2021b). The national plan modelling also took into account the changing role of TTIQ at high numbers of cases, at which point it was expected to become less effective, which would have the compounding effect of allowing the rate of transmission to increase further. Modelling of the relative effect of 'optimal' and 'partial' TTIQ on transmission, and the conclusion that the nation could be safely reopened at 70 per cent vaccine coverage with optimal TTIQ, or at 80 per cent vaccine coverage with partial TTIQ (Australian Government Treasury, 2021), represents a reflexive attempt to grapple with the limits of what could be known and what could be controlled once there was high prevalence of COVID-19 within the community. With the acknowledgement that not all cases would be detected and isolated, nor all contacts traced and isolated, a new model society was being established in which effective governance no longer hinged on the precise enumeration and management of cases.

The abstraction from the absolute to the relative can be seen as several of the south-eastern states confronted the question towards the end of 2021 of how to exit the lockdowns that had been implemented to attempt to contain the Delta variant. Community transmission of COVID-19 continued to occur in NSW and Victoria, in particular, despite the strict restrictions in place. This was seen to call into question whether the Doherty Institute modelling underpinning the reopening plan, which started with an outbreak of 30 cases, was rendered outdated by daily case counts of several hundred in NSW by late August 2021 (ABC, 2021). Following some debate in the media, the modelling team was tasked by the federal government with 'tweaking its assumptions to reflect the current situation, and seeing what comes out of the model' (Lowrey & Hitch, 2021). The Institute subsequently confirmed that 'an increase from tens to hundreds of seeded infections results in a leftward shift of timing of the epidemic […] but [it] does not differ in overall impact' (Doherty Institute, 2021b). The modellers were also incorporating new evidence about the Delta variant as it became available, but 'thankfully, by the time you update everything, it doesn't make any difference to the targets and thresholds' [19]. It was therefore considered that the protection offered by high rates of vaccination means that case numbers in these states did not need to be brought back down to zero before lockdown restrictions were eased.

When high rates of vaccination were observed to have a dampening effect on transmission in November 2021 – before the Omicron variant caused a dramatic increase at the end of the year – some modellers described feeling 'almightily relieved when you start seeing case numbers turning over in NSW and then in Victoria, and thinking, "It works!"' [19]. And when the Australian public took up COVID-19 vaccines and achieved a rate of over 90 per cent with two doses by the end of 2021 (Australian Government Department of Health and Aged Care, 2021), it was described as another unanticipated outcome, echoing the 'pleasant surprise' of the public's response in the early phase of the pandemic. One of the modellers involved in devising the national plan recalled that the 80 per cent target had been considered 'aspirational' and therefore that 'the public delighted us' when it significantly exceeded all targets [19]. At the end of 2021, while the Omicron variant was causing cases to rise to higher numbers than had been seen before in Australia, most states and territories were starting to reopen, undoing all local elimination previously achieved (Chrysanthos, 2021; Scott, 2021; Taylor, 2021, December 19). A model society, with key parts played by models, modellers, policies, publics and the interactions between them, had enacted COVID-19 as a risk that, with a high proportion of the Australian population vaccinated, could be safely lived with.

Conclusion

We have argued that, over the course of the first two years of the COVID-19 pandemic, Australia's response gave rise to two distinct forms of what we call 'model society', which is characterised by a mode of governing with and through models, as well as the vision for society that is produced through this governance. These 'model societies', which saw elimination unexpectantly achieved and then incrementally undone, complicate the dominant view of the elimination of infectious

disease as a desirable end to be sought through targeted intervention (e.g. Whittaker et al., 2014). More specifically, they underline the ways that evidence-making interventions (Rhodes & Lancaster, 2019), in which models typically play a central part in the pursuit of elimination, generate relations and performative effects that, in their emergence, have the potential to redefine objects and modes of governance.

In the first iteration of 'model society', mathematical models orientated policy-makers towards a rough outline of the challenge that might be posed by COVID-19 and pointed to the role that some public health interventions could play. Here, models tended towards an imagined potential of catastrophe, of pandemic made 'big', to afford pre-emptive policy action in the face of the unknown (Lakoff, 2017; Rhodes & Lancaster, 2022a). As the spread of COVID-19 became contained and its possible reentry into Australia closely monitored, models enabled the constant assessment of risk, the refinement of public health measures and an iterative rearticulation of policy goals. COVID-zero emerged as the objective and mark of success of this model society only as this approach proved 'unexpectedly' successful and approaches to monitor and understand risk were refined, including through the development of the transmission potential concept – with the effect of further consolidating the measures to contain the spread of the virus. In the second model society, models were called upon to assist in navigating a path *away from* COVID-zero, prompted by the availability of vaccines and by the increasing tension between competing social and economic imperatives. Playing a more explicit role in defining the goals of society to balance these imperatives, models here provided a high-level framework for the realisation of a 'transmission-reducing' strategy through the iterative adjustment of local response.

Throughout these phases of Australia's pandemic response, the very objective of the response has been at issue. Models of current and future transmission dynamics have reshaped the ends to which policy response is directed as well as the ways in which its success is known. Where the first of these model societies was characterised by the *absolute* – including numbers of cases, or days with or without community transmission – the 'transmission-reducing' model society was made sense of in more *relative* terms centred on rates of vaccination, which afforded a latitude in the evidence-making of Australia's reopening. Case numbers, and the status of individuals as infected or not, were displaced by vaccination rates, a population-level measure, as the key metric. The phases defined in the national plan for the progressive reopening of society were not associated with specific dates but rather pegged to vaccination rates. What is said to be a relative 'simplicity' of the role of models in the first phase of the pandemic, at least in initially gesturing to catastrophic potentialities in order to prompt governments to 'do something', was replaced by what is referred to as considerably greater complexity. Success itself is no longer defined by the presence or absence of the virus but in achieving a balance between competing values.

Throughout these phases, outcomes can also be seen as the emergent effect of the engagement of models, modellers and decision-makers. Considerable collective *work* on the part of many actors was involved in achieving elimination – even as it was not their explicit goal as such – as well as its undoing. At no point in the periods discussed can models be said to have straightforwardly prescribed the policies that were enacted by governments – as might be imagined from the way that policy-makers have at times throughout the pandemic assured publics that they are 'following the health advice'. Nor was it the case that models merely supported actions already envisaged. Rather, the assemblages made up by these actors, both human and non-human, can be said to collectively produce outcomes that may exceed the intentions and agency of any one actor, as is apparent in the 'unexpected' success and 'collateral reality' (Law, 2011) of Australia's early policy response to COVID-19.

Finally, these 'model societies' can be seen as the product of attempts to manage the irreducible uncertainties of a global pandemic. These uncertainties reside in the globalisation of doubt, linked with the uncertainties of modernisation in an unpredictably changing environment (Hinchliffe et al., 2021); uncertainties that the concept and sciences of risk emerged to reflexively grapple with, according to Beck's account of risk society (1992). In these model societies, models have

played a key role in enabling action in the absence of knowledge of the virus and its transmission. They do so by offering a way of managing risks *as if* they can be known, performing *evidence enough* as the basis of policy interventions. This is particularly apparent in the way that the transmission potential concept sought to quantify the potential of a virus to spread in a society in which it was not even present. Throughout the first two years of Australia's experience of the COVID-19 pandemic, models have been counted upon to know the transmission of the virus, in order that it be governed.

Notes

1. This sense is related to broader, not-strictly-mathematical ways of thinking about models, including as a test case, blueprint or ideal type displayed for replication. Common to all senses of the term is that a model can reveal success (Østebø, 2021).
2. The allocation strategies explored were a) 'oldest first', whereby vaccinations are prioritised from oldest to youngest; b) '40+ years first', whereby vaccinations are prioritised from age 40 upwards and then from 16 to 40 years; and c) 'all adults', whereby vaccinations are not prioritised in any particular age order.

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