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MODELLING PANDEMIC

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Modelling Pandemic

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Abstract

Axiomatic, everywhere, to experiences of the COVID-19 pandemic are *models*: models for prediction, models for understanding, models for projection, models for story-telling. Struggles over the interlocking global crises that the pandemic has provoked—and what to do about them— translate, in many places, into struggles over the parsimonious representation of that which exceeds observation. Which, then, are the models wielding greatest authority in the COVID-19 pandemic? How are they put together and disseminated, and by whom? What claims and hierarchies are embedded in them, not just in their explicit assumptions but also in their timescales, aesthetics, and semiotics? Where lie their centres and peripheries? With what or whom are they most concerned and to what or whom are they inattentive or indifferent? To take account of the world-making and -remaking ramifications of COVID-19, we must register and read closely how it is being modelled.

Keywords: Models, knowledge, power, regulation

I Introduction

"We need new models" has been a regular refrain amid the COVID-19 pandemic. New models of public-private partnership for vaccine delivery; new models of disease spread and mortality characteristics; new models of aged care; new, more equitable economic models: all these and more have been called for of late. In these various calls, the term "model" means slightly different things. Yet the term is nonetheless a recurrent point of reference. It encapsulates a set of intersecting knowledge practices now ubiquitously understood as essential for navigating the complexities of contemporary life. The cry "we need new models" laments uncertainty, fear and suffering and expresses an aspiration that these may be surmounted through human ingenuity, computationally enhanced. What the "model" signifies in these calls is a world of which people may yet be mindful modellers.

As these calls illustrate, modelling has been central to prevailing experiences of, and debates surrounding, the COVID-19 pandemic. Indeed, the pandemic may be said to exist as a model, or a composite of models, in many people's perception. Consider, for example, the situation of lay people logging on to Johns Hopkins University's COVID-19 dashboard – at one point reported to be receiving a billion hits per day. To do so is to grasp the scale and properties of the pandemic by recourse to mathematical models, albeit relatively simple ones. By working backwards from one other genre of pandemic-related modelling output – social distancing requirements – this chapter probes how certain types of model, and their instantiation in law, policy and official guidance, have promoted particular understandings of social life. In so doing, this chapter explores something of these models' centres and peripheries, foregrounds and backgrounds, hierarchies and priorities, preoccupations and blind spots.

Models are not monstrous. The aim of this chapter is not to try to expose modelling as some malevolent or suspicious force in economy and society in times of COVID-19. The goal is likewise not to argue about contending models' relative merits nor advocate for particular models' improvement in one way or another. Rather, this chapter draws attention to how significant a force of economic and social ordering modelling has been in this global pandemic. It aims to show how broad of range of people and institutions have stakes in the preference of one modelling technique over another, and in the choices, distinctions, links and hierarchies invariably embedded within models. It seeks to demonstrate, as a consequence, how worthy of careful, informed critique, and cross-referencing against other knowledge forms, are influential models. Modelling is an invaluable practice of social and economic ordering and analysis; it ought not be an indubitable one.

II Models and Modelling

To embark on the study just outlined requires something to be said about modelling as a genre of knowledge practice and about what the term "model" may imply in the context of pandemic-related knowledge production. This entails generalization across a number of distinct professional practices, each of which merits, and has attracted, dedicated investigation. These include: scientific modelling; mathematical modelling; financial and economic modelling; and social modelling.

Across these different areas of work, the word "model" denotes a representation of, or proxy for, some target about which knowledge is sought, whether that target be actual or ideal (Portides, 2013). A model describes a structure or puts forward an archetype or set of archetypes (OED Online). A model is also an analogue in the sense that it typically posits relations of similarity and difference to some worldly phenomena, or to a theoretical description of some worldly phenomena. Models' analogical status does, however, vary in degree. Some models are designed to be positive analogues of the "real world". An example would be models used in species distribution modelling, to try to predict the distribution of an extant species over space and time. Others are "working pictures" developed for instrumental purposes and then dispensed with – at most, only ever formally analogous to something in the world (Hesse, 2017; 1966). One example of the latter would be English chemist John Dalton's early nineteenth-century modelling of the atom on a hard, wooden ball like a billiard ball. The idea that the model necessarily represents something other than itself may also be strained. Some models produce data in their own right about their own rendering of non-existent phenomena (as when Daisyworld computer simulation models may produce data about planetary scenarios such as life never having existed on Earth) (Huneman and Lemoine, 2014). The broad genre of knowledge practice with which this chapter is concerned is that involved in making, analysing, disseminating, predicting with and otherwise being informed by models.

Within this expansive category of knowledge practice, scientific modelling is a distinct and influential strain. Many have noted the centrality of modelling to science. Models in science may be material (physical, such as a scale model of the DNA molecule) or formal (such as a wave equation) (Hesse, 2017). Put another way, scientific models may be "in vivo", "in vitro", or "in silico" (Huneman and Lemoine, 2014). They may take the form of particular organisms standing in for other species or taxa for purposes of investigating certain biological processes or testing pharmacological interventions. The *drosophila* genus of fruit flies used by geneticists is an example. They may be comprised of laboratory reproductions of particular biochemical processes. One example is a model of osmotic shock (sudden change in salt concentration in surrounding solution) in yeast or *Escherichia coli* cells induced for biochemical analysis. Or they may take the form of computer simulations, such as cellular automata and other agent-based models, representing the behaviour of complex systems over time.[i]

A distinguishing characteristic of scientific models – as distinct from scientific "laws" – is their contingency, partiality and amenability to pluralism and iterative adjustment. As Schummer has observed, "[d]ifferent models for the same field of application can peacefully coexist and usefully complement each other, because they might employ different approximations…Both laws and models are comparable tools for explanations and predictions, but laws assume exclusive explanatory power while models can explain only those aspects [that] they have been built" to explain (Schummer, 2014, p.S98). Although laws may approximate and vary in scope, a law proposed in science is typically designed to cover a broader class, and to issue more enduring precepts, than a scientific model.

Mathematical modelling often intersects with scientific modelling. Computer simulations, for instance, may be regarded as instances of both. Nonetheless, mathematicians' usage of the term "model" diverges somewhat from its typical usage in science. As noted above, mathematical modelling sometimes entails description of a "real world" or ideal system using mathematical concepts and language. Yet mathematicians also use the term model to denote a structured realization or representation of data (comprised of variables, equations and assumptions or boundary conditions) in which all elements of a particular theory are satisfied (Suppes, 1960). Some mathematical models may also represent results from the testing of ad hoc hypotheses without necessarily expressing a fundamental theory in full; the liquid drop theory of nuclear structure does not, for example, explain all nuclear phenomena (Portides, 2011, 2013). Data scientists' use of the term "model" is more akin to the latter: the term refers to a standardized, reproducible set of procedures that may be deployed predictively against data, often derived from the processing of training data by a learning algorithm.

Financial and economic modelling is that branch of the practice concerned with creating textual and mathematical representations of markets and economic processes. Modelling is used to guide investment decision-making, product pricing and risk assessment, among other practices. In this context, the concern of modelling is not generally with faithful reproduction of the world. Rather, the aim of modelling is the approximation of certain economic or financial phenomena, by recourse to stated assumptions, from the manipulation and analysis of which certain insights and predictions may be drawn. A "good" model, according to prevailing expectations in much of this field, is economically plausible (albeit inexactly so), analytically tractable, and useful for market purposes. That a model's assumptions may be unverified or somewhat unrealistic does not generally consign that model to uselessness. In this mode, modelling has been fundamental to the burgeoning of financial economics, and associated trading activities, since the mid-twentieth century (MacKenzie, 2006).

Social modelling likewise grew in prevalence and influence over the second half of the twentieth century, building on the historical-comparative sociology of Max Weber and Weber's use of ideal types (Weber, 2019). To describe and compare social models is to subscribe to the idea that path dependency yields certain distinctive patterns or "models" of social, political and economic organization, the merits and demerits of which may be compared. Europe, East Asia, particular countries, or other portions of the world are "seen as containers of specific and separate national and regional cases of economic and social performance, cases that are defined through comparison and demarcation from each other in terms of similarities and differences" (Stråth, 2007, p.336). Entanglements, interdependencies and obscurities tend to be de-emphasized so that relatively clear-cut models of society may be described and compared. A model, in this context, is a pre-formed, unitary example used as a basis for evaluation and experiment. The "model" in this setting is more analogous to a scientific animal model than to a computer simulation. Nonetheless, the activity of modelling at issue (namely, description and comparison) stands quite apart from the technical practices of scientific, mathematical or economic modelling. This and all the other modes of modelling described above have been brought to bear, in combination, upon the COVID-19 pandemic.

III Modelling COVID-19

SARS-COV-2, the novel coronavirus that causes COVID-19, and the associated pandemic, have been the focus of extensive scientific and mathematical modelling, through computer simulation especially (Jewell et al, 2020; Adam, 2020). Models employed have included SIR or SEIR models: epidemiological models that compute the number of people theoretically infected, or projected to be infected, with a contagious illness in a given population over time by assigning numbers of people to various compartments: susceptible, exposed, infectious, and removed (that is, immune or deceased). Propagation and diffusion of SARS-COV-2 have also been analysed using genetic evolution models, representing incidence of mutation and mutation rates across time and space. Similarly, interactome models of SARS-COV-2 in humans have been used to study how viral-host interactions affecting proteins and other molecules within cells may regulate associated pathogenesis.

Certain numbers derived from scientific and mathematical modelling have loomed especially large in popular consciousness and governmental communication about the pandemic, two examples being the basic reproduction number (R_0) and effective reproduction number (R).[ii] Likewise, particular instances of modelling appear to have been particularly influential. The impact of the modelling work of mathematical epidemiologist Neil Ferguson and his team at Imperial College London is a noteworthy example. Projections from their models reportedly prompted changes in UK governmental policy (Adam, 2020).

Financial and economic modelling of the actual and projected impacts of COVID-19 has likewise been widespread. OECD economists have, for instance, modelled base-case, best-case and downside scenarios of the pandemic's economic effects using the NiGEM Model: a quarterly econometric model based on real economic data from 46 countries (28 from Europe, including the U.K.; eleven from Asia and Australasia, six from the Americas, and one from Africa) and some 19 regions maintained and by the National Institute of Economic and Social Research in Britain (Boone et al., 2020). These modellers' focus has been on extraordinary disruptions produced by the pandemic – interruptions in supply, declines in demand, and loss of confidence – rather than pre-existing, structural features of the economy bearing upon COVID-19 outcomes, such as inequality, urbanization, or the distribution of access to healthcare. In this account, the pandemic's economic repercussions have been cast as "fallout" and the emergence of the SARS-COV-2 virus characterised as a "hit" and a "shock", as though analysing a military attack, industrial accident or natural disaster (Boone et al., 2020). We will return to these story-telling dimensions of modelling practice below.

Social modelling of a less technical kind has also been apparent in analyses of the COVID-19 pandemic. In scholarly, clinical and public discussion of the pandemic, certain national archetypes of COVID-19 policy response have been popularised and compared. Those advancing particular policy recommendations have frequently done so with reference to one or other national model – the "Singapore model", for example (e.g., Wei, 2020). The "Swedish model" – a "relaxed strategy" premised on the build-up of herd immunity within a national population – has been a particular target of scrutiny and debate (e.g., Ramachandran, 2020).

In these various settings, COVID-19 modelling has been a mode of argument as well as an analytical practice. To model is to give shape, to craft, or to fashion. Models assemble certain elements and entities and "offer them to experience already linked together" (Foucault, 2001, p.389). When models feature humans, or human proxies, they confer upon those figures certain characteristics, functions, needs, and desires, and strip away other properties. Modelling entails determining precisely what will suffice to approximate that which is modelled, or otherwise inform decision-making on that subject matter. In so doing, modelling involves carving out cores (or determining what is essential) and dispensing with inessential aspects of phenomena represented. As will become apparent from the discussion in Part IV below, these norms and priorities often travel and persist via the models in which they are embedded.

Models of the COVID-19 pandemic have proliferated along with the profusion of relevant scholarly literature. Even so, as noted above, a relatively small subset of the models advanced in this scholarly work have found expression in policy statements, official recommendations, and legal norms designed to counter the pandemic, limit its spread, and mitigate its adverse effects. The next section will focus on one genre of law and policy output related to COVID-19 that is underpinned, in large part, by modelling: social distancing requirements.

IV Social Distancing as a Modelling Output

Some commentators have asserted that social distancing recommendations pronounced in the face of the COVID-19 pandemic "are based on studies of respiratory droplets carried out in the 1930s" (Prather et al., 2020). The provenance of these policies is, however, difficult to establish with such precision; their evidence base is more cumulative and collage-like than this suggests (Qureshi et al., 2020). Nonetheless, it is certainly the case that modelling of the dispersal of droplets, and of associated disease transmission, underpins the policies adopted around the world to try to ensure that people keep their distance from one another. Diseases, like COVID-19, that partially manifest in respiratory symptoms, are known to be passed on through airborne transmission of virus-containing droplets emitted during breathing, speaking, coughing and sneezing. Prior decades' modelling of the emission, movement and settling of these droplets makes up a key part of the knowledge base on which social distancing policies are founded. These encompass policies effecting school closure, workplace and enterprise closure or circumscribed operation, case isolation, and a range of other measures designed to reduce interpersonal contact. For purposes of this discussion, let us focus on recommendations to maintain a minimum amount of physical distance among people.

From the early days of the COVID-19 pandemic, the World Health Organization (WHO) advised people to keep at least one metre or about three feet away from others. China, Egypt, France, India, Liberia, Norway, Singapore and Thailand and other nations issued similar recommendations, as did Denmark (after reducing the minimum recommended distance from two metres to one in May 2020). The Centers for Disease Control and Prevention (CDC) in the U.S. recommended that people maintain a distance of at least six feet (or 1.8 metres) between themselves and others. Meanwhile, Australia, Bolivia, Germany, Italy, the Netherlands, Serbia, Spain, South Africa and other nations have indicated that 1.5 metres is the minimum distance from others that people should maintain. The U.K. initially recommended people keep at least two metres or approximately 6.5 feet away from others, but dropped this to "one metre plus" as of early July 2020, while recommending adoption of other measures to prevent viral transmission. Botswana, Canada and Vietnam advised people to stay at least two metres apart. South Korea suggested likewise, while accepting one metre as a minimum distance in certain environments.

As well as being the subject of health advice and other "soft" governance measures, these minimum social distances have been rendered enforceable in a range of ways backed by the coercive power of the state. Legislation and regulations requiring the closure of schools and certain businesses, stipulating the conditions under which schools and businesses may open, and prohibiting gatherings of certain sizes: these are illustrative of the hardening of social distancing requirements around the world. In many jurisdictions, those who congregate or operate in breach of these may be subject to heavy fines or even jail terms. All states in Australia, for example, have introduced penalties individuals and businesses conducting themselves in breach of social distancing requirements. In the State of New South Wales in Australia, orders made under the state's Public Health Act enable individuals to be fined of up to AUD$11,000 (nearly US$8,000) initially (and more for continuance), or sentenced to six months in jail, for violating such restrictions. In India, jail terms of up to two years may be imposed, alongside fines, upon those who refuse to comply with public health directions issued under the Disaster Management Act. In Singapore, regulations promulgated under the Infectious Diseases Act have made breaches of social distancing measures punishable by fines (up to SG$10,000 or nearly US$7,500) or imprisonment of up to six months or both. In Denmark, violations of restrictions imposed under the Danish Epidemics Act are punishable by fines (up to DK40,000 or nearly US$6,500 per instance, increased for repeat offences) or jail terms of up to six months. Across the U.S., noncompliance with regulations and executive orders mandating social distancing may attract civil or criminal penalties, including (potentially) orders to suspend business operations, license revocations, misdemeanour arrests, fines or possible imprisonment (typically for terms up to 30 days, but in some jurisdictions – Indiana, for example – up to 180 days).

The rationales offered by the WHO when communicating these distancing requirements to the public made implicitly clear their foundation on the modelling of muco-salivary respiratory droplets' exhalation and airborne movement. When explaining why people must stay at least one metre apart, the WHO website states "[w]hen someone coughs, sneezes, or speaks they spray small liquid droplets from their nose or mouth which may contain virus. If you are too close, you can breathe in the droplets, including the COVID-19 virus if the person has the disease". Within months of such guidelines being issued to deal with the COVID-19 pandemic, however, researchers attacked the soundness of their evidence base and questioned the correspondence between distancing recommendations and insights derived from scientific modelling. As noted above, prevailing social distancing rules have been broadly founded on assumptions that the SARS-CoV-2 virus is primarily transmitted via respiratory droplets, larger versions of which had been shown to settle fairly quickly after emission under the force of gravity. Research making use of technology capable of detecting extremely small (submicron) aerosols suggested, however, that airborne transmission could occur via a continuum of droplet sizes embedded in clouds of exhaled air. Smaller aerosolized droplets have been shown capable of remaining airborne for many hours and travelling distances far greater than the one or two metres specified for social distancing, with environmental factors such as ventilation bearing significantly on viral transfer. In short, evidence supportive of physical distancing of between one and two metres has been shown to be sparse or outdated (Bahl et al., 2020; Prather et al., 2020; Qureshi et al., 2020). If social distancing requirements were founded on models of airborne rather than droplet transmission, the distances mandated could well have been much greater, or regulatory requirements might have focused more on ventilation conditions, for example.

The particular models by which they have been and should be informed may be a matter of debate, yet social distancing regulations remain an output of modelling nonetheless. What seems apparent in the convergence of national policies around a relatively limited range of options for mandating social distancing – all between the one-to-two-metre range – is the cumulative impact of model-borne thinking and practice across several fields. Scientific modelling underpinned the identification of a risk of viral transfer via muco-salivary droplets, and the prospect of its mitigation through human bodies' physical distancing. Economic modelling encouraged governments and international organizations to focus on policy arrangements that seem analytically tractable, and useful or "saleable" for current market purposes, even if the assumptions on which they are based may be questionable. Social modelling supported the idea that collective social conduct is best organized, grasped, and evaluated by recourse to a pre-existing array of patterns or archetypes, assigned to national containers. It fostered a tendency to take something of the shelf, as it were, rather than approach social analysis and policy-making *ab initio*. In all these ways, social distancing policies are artefacts of a modelled world.

V Modelled Worlds

What, then, are the characteristics of the modelled worlds to which social distancing policies testify? Much of the scholarly commentary on the epistemology of models from outside the natural sciences and mathematics fields has revolved around their potential to mislead. Of particular concern has been models' propensity to generate an illusion of truth, integrity and predictive capacity even while exhibiting any number of weaknesses, including: poor or biased input data; empirically incorrect assumptions; highly sensitive estimates; thin historical analysis with inattention to prior model-based outcomes; lack of transparency; and want of consultation with domain experts (Ellison, 2020; Ioannidis, 2020). In relation to the COVID-19 pandemic specifically, some have claimed that efforts to forecast its trajectory and impact on the basis of modelling have "largely failed" despite "involving many excellent modelers, best intentions, and highly sophisticated tools" (Ioannidis, 2020, p.4).

Here, the relative truth value of different models is not of immediate concern. Instead, the focus is on the social and economic ordering work that they do. Whether or not COVID-19 modelling has succeeded or failed in particular instances, and regardless of the strength or weakness of particular models, models are nonetheless offering up particular renderings of the pandemic and the world it has afflicted. Models are artefacts with politics; they champion certain arrangements of relation, power and authority over others (Winner, 1980). In this light, let us identify some recurrent features of models representing the COVID-19 pandemic and of the world that they offer to experience.

First, these models are pro-social insofar as they tend to incline modelled units toward one another and highlight reciprocal impacts among them (harmful as well as beneficial ones). Ideals of absolute autonomy or libertarian freedom are not readily secured by modelling because models are by nature about interactions and interdependencies. A modelled COVID-19 pandemic is a systemic phenomenon within which boundaries at all scales – biological, territorial and political – are permeable. Those who envision themselves as isolates – people such as the "solitary non-employed persons" who effect "hikikomori", or complete social withdrawal, as described in the Japanese labor economist's Yuji Genda's work (Genda, 2019) – find no place for their self-understanding in a modelled world. It would be a mistake, however, to equate models' pro-sociality with even-handedness or disinterest. In their pro-social dimensions, models tend to put forward an impression of inclusiveness that belies their selective slicing and differential weighting. Models' partiality may be methodologically justified, but it cannot be wished away. The sociality of models is a classified and ranked condition of unavoidable connectedness.

Second, the modelled world of the COVID-19 pandemic is highly governable. For all the challenges posed by the pandemic, the efficacy of human governance in the face of it is more or less presumed. Borders may be closed. Bodies may be rearranged in space and time, contained within categories (nations and genders, for instance), and disciplined to adhere to those arrangements. Modelled worlds are amenable to varying degrees of human mastery (depending on their stochastic dimensions and error rates), but most tend to have humans at both their centres and their helms. The systems that they represent – the worlds that models make – are largely anthropocentric, even though the precipitant for their creation may have been viral zoonosis (as in the case of SARS-COV-2). At the same time, both models and public communications referencing models tend to presume broad familiarity with modelling practices among their audiences. This is despite the fact of "pervasive misperception of models" having been well documented, including among the literate and otherwise privileged (e.g., Wagner et al., 2010).

This presumed governability of the world that models make is conditional upon screening out sites and modes of relative ungovernability, and those for whom modelled messaging makes little sense. Those people for whom governance measures modelled (such as social distancing measures) are unlikely to be effective – say, slum-dwellers living under conditions not amenable social distancing or disabled persons requiring intimate care – may only register in the unexplained negative spaces of a model: perhaps as a percentage of the population presumed non-compliant, or as an error rate. This is true, too, of people that tend to be represented poorly or scantly in models for other reasons, such as those about whom there is a paucity of epidemiological data.[iii] Those negative spaces may be read to invite governmental intervention, or they could be interpreted as too intractable or insignificant to be worthy of attention. Either way, those upon whom prevailing governance techniques are more likely to have clear purchase, and those to whom model-based communications speak most easily – they are first in line as objects of analysis and care when modelling a pandemic.

Third, and finally, modelled worlds of the COVID-19 pandemic are event-oriented. It was noted above how models of the economic effects of the pandemic has tended to cast the emergence of the SARS-COV-2 virus as a "shock". This is understandable, notwithstanding the many settings in which a zoonotic pandemic of this kind had been anticipated and projected. Nonetheless, it has implications for how reactions to the virus are framed. When the pandemic is modelled as a singular event, it is not cast as the culmination of a known historical processes, such as deforestation and habitat destruction (often highlighted as causal factors in zoonosis) or the underfunding or paucity of public healthcare (again, a recognised factor in COVID-19 outcomes). This tends to encourage reactions framed as counter-events: reactions of a staccato, finite nature.

Most commonly, the effects of the SARS-COV-2 virus are modelled over a definite, relatively short time span. Models are generally not crafted to account for long-term factors contributing to the virus's emergence in humans, nor as if this virus were likely to become endemic. This is in part because of the "disappointingly short horizon of predictability for epidemic models" (Wong et al., 2020). This has the effect of bringing legal and policy measures introduced in the face of the pandemic neatly under the umbrella of emergency, prompting recourse to extraordinary powers designed for disaster and relatively unfettered by "normal" accountability processes. It also delinks the social welfare measures that have been introduced in many jurisdictions to deal with the pandemic from the routine infrastructure of state support. As a consequence, shortfalls and vulnerabilities illuminated afresh by the pandemic may be more likely to be addressed with piecemeal, short-term measures rather than dealt with in enduring ways. When we model the COVID-19 pandemic as an event, it becomes harder to understand it as something to which many routine human practices have contributed (such as, say, changes in macroeconomic policies affecting deforestation in low- and middle-income countries: Angelsen & Kaimowitz, 1999). This suggests little occasion to revisit the past or to try to reorient those pre-existing routines.

VI Conclusion

The world that we have come to know over the course of the COVID-19 pandemic is, in many respects, a modelled world – shaped by scientific, mathematical, economic and social models and their intersection. This is a world of unavoidable interdependence. It is a world amenable to human governance and apportionment, seemingly without too much agony or ambivalence. It is a world comprehensible and addressable in terms of relatively discrete, recent events. It is, as consequence of these features, a world of priorities and blind spots. That which may be well modelled in these terms tends to occupy the foreground of public perception and debate. Those phenomena and human experiences poorly aligned with a world so framed – the disconnected, the hybrid, the persistent, the nonhuman, the unstudied and so on – become harder to register and accommodate amid first order concerns. As noted above, "we need new models" has been a regular refrain amid the COVID-19 pandemic. This is justified. Yet perhaps, alongside new models, we need to make more room for cross-referencing these against unmodelled knowledge about the COVID-19 pandemic as well, including forms of knowledge most strongly associated with the humanities, social sciences and creative arts (narrative knowledge, for instance). In these and other ways, scholarly, policy and community decision-making concerning the pandemic must remain alive to the politics of modelling. It is a politics in which we all now have a stake.

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[i] The term "agent-based models" refers to computer models that stage recurrent, competitive interactions among elements representing autonomous decision-making entities called agents. Within the ambit of the model, they allow for an individual agent's behaviour to depend upon the state of its neighbourhood and its interactions with other individual agents, and require data on these interactions (Bonabeau, 2002). Although some agent-based modelling employs differential equations, it is often distinguished from equation-based modelling (Parunak et al., 1998). The latter entails the construction of models comprised of equations expressing relationships among certain classes of observable or attributable characteristics, and the evaluation of these equations, and the change in the characteristics that they produce, over time. Agent-based models create something of a virtual world populated by individual archetypes, whereas equation-based models assemble and work with quantifiable categories.

[ii] With respect to any one disease, the R_0 and R numbers express, respectively, the average number of secondary infections produced by a case of infection in a population without immunity and the average number of people to whom one infected person is actually passing the virus at a given time.

[iii] Korngiebel, et al. (2015) observe that certain populations, such as indigenous peoples, are poorly represented in epidemiological data sets for a range of reasons that may include "culturally discordant survey content", "ineffective data collection methods", and "ethnic and racial misclassification" (at p. 1744).