Dear Lady Hallett and the Solicitors' Team

As requested, please find answers below to the queries in the questionnaire that you sent me by email.

If any further information is required, please do not hesitate to get in touch.

Yours sincerely,

Sam Moore

Module 2 of the UK Covid-19 Public Inquiry Request for Evidence under Rule 9 of the Inquiry Rules 2006
Reference for Request - M2/SAGE/01/SXM

Dr Sam Moore – Epidemiological modeller.

03/2020 – Present

Postdoctoral Research Assistant, Funded by DHSC through the *Mathematical & Economic Modelling for Vaccination and Immunisation Evaluation (MEMVIE)* project.

University of Warwick, Zeeman Institute for Systems Biology and Infectious Disease Epidemiology Research.

EDUCATION

09/2017 – 01/2020	**PhD:** *Dynamics and interactions of infections on networks*, University of Bath
09/2016 – 09/2017	**MRes:** *Statistical applied mathematics*, University of Bath
09/2009 – 06/2014	**MMath:** *First class honours*, University of Edinburgh

PUBLICATIONS

Keeling MJ, Dyson L, Tildesley MJ, Hill EM, Moore S.
Comparison of the 2021 COVID-19 Roadmap Projections against Public Health Data.
Nature communications. 2022.

Moore S, Hill EM, Dyson L, Tildesley MJ, Keeling MJ.
The impacts of increased global vaccine sharing on the COVID-19 pandemic; a retrospective modelling study.
medRxiv. 2022.

Keeling MJ, Moore S.
An assessment of the vaccination of school aged children in England.
BMC Medicine. 2022.

Moore S, Hill EM, Tildesley MJ, Dyson L, Keeling MJ.
Vaccination and non-pharmaceutical interventions for COVID-19: a mathematical modelling study.
The Lancet Infectious Diseases. 2021.

Moore S, Hill EM, Dyson L, Tildesley MJ, Keeling MJ.
Modelling optimal vaccination strategy for SARS-CoV-2 in the UK.
PLoS computational biology. 2021.

Dyson L, Hill EM, Moore S, Curran-Sebastian J, Tildesley MJ, Lythgoe KA, et al.
Possible future waves of SARS-CoV-2 infection generated by variants of concern with a range of characteristics.
Nature communications. 2021.

Keeling MJ, Thomas A, Hill EM, Thompson RN, Dyson L, Tildesley MJ, et al.
Waning, Boosting and a Path to Endemicity for SARS-CoV-2.
medRxiv. 2021.

Moore S.
Dynamics and interactions of infections on networks.
University of Bath; 2020.

Moore S, Rogers T.
Heterogeneous node responses to multi-type epidemics on networks.
Proceedings of the Royal Society A. 2020.

Moore S, Rogers T.
Predicting the speed of epidemics spreading in networks.
Physical review letters. 2020.

Moore S, Morters P, Rogers T.
A re-entrant phase transition in the survival of secondary infections on networks.
Journal of Statistical Physics. 2018.

Participation and contribution to groups

From April 2020 up until the present (September 2022) I have worked as a PDRA within the University of Warwick, as part of the *Mathematical & Economic Modelling for Vaccination and Immunisation Evaluation II* (MEMVIE II) project funded by the NIHR with Professor Matt Keeling as Principal Investigator. My work over the pandemic period has been primarily in support of Professor Keeling's contributions, particularly in relation to modelling work concerning the UK's vaccination program and the relaxation of NPI measures forming the *Roadmap* out of lockdown.

In the course of doing this I attended the majority of SPI-M-O meetings in the period between November 2020 and March 2022, two JCVI full committee meetings, and a number (5-10) of smaller subgroup meetings supporting JCVI decisions. In the JCVI meetings and a small number of SPI-M meetings I directly presented and answered questions relating to modelling work undertaken with colleagues from the University of Warwick, while in the remaining majority of SPI-M meetings I acted simply as an observer, in order to keep up to date with relevant modelling work, concerns and needs.

Summary of contributing documents

Vaccination

07/11/20	Optimisation of Rapidly Delivered Vaccine. Moore & Keeling	SPI-M
03/12/20	COVID vaccine deployment scenarios. Moore, Hill, Tildesley, Dyson, Keeling	SPI-M SAGE 72
17/01/21	COVID vaccine impact forecast	SPI-M
21/01/21	COVID vaccine impact forecast	SPI-M SAGE 76
31/01/21	Relaxation of NPI as vaccination proceeds	SPI-M
03/02/21	Relaxation of NPI as vaccination proceeds	SPI-M SAGE 79
09/03/21	Comparison of realised strategy vs second dose prioritisation	SPI-M
11/10/21	Speculations on the long-term dynamics of COVID-19: 2022 and beyond	SPI-M
Summary. Although much of the vaccination workwent to JCVI, it is impossible to consider prediction of the epidemic without taking account of the action of vaccination. The earliest work looked at the potential for vaccination to reduce R, this was performed with very limited data on the behaviour of vaccines and we conclude that the vaccine will have the		

greatest impact when targeted to the elderly and vulnerable – it is better to give protection to those most likely to experience severe illness, rather than those most responsible for transmission. This work was later published as: Moore, S., Hill, E.M., Dyson, L., Tildesley, M., Keeling, M.J. (2021) Modelling optimal vaccination strategy for SARS-CoV-2 in the UKLink opens in a new window. *PLoS Comp. Biol.* **17**(5): e1008849. https://doi.org/10.1371/journal.pcbi.1008849
The next series of papers looked in more detail at the timing of vaccination and whether this allowed the rapid relaxation of non-pharmaceutical interventions. This work was repeated as we needed to account for both the emergence of the Alpha variant and changing data on vaccination efficacy. We conclude that: "A high efficacy vaccine that provides a high level of transmission blocking offers a means of eventually relaxing controls without suffering a large subsequent wave of hospitalisations and deaths", however we note that relaxation of controls has to be slow to avoid a rapid spike in cases and severe disease. This work was later published as: Moore, S., Hill, E.M., Tildesley, M., Dyson, L., Keeling, M.J. (2021) Vaccination and non-pharmaceutical interventions for COVID-19: a mathematical modelling study. *Lancet Infectious Diseases.* **21**(6): 793-802. https://doi.org/10.1016/S1473-3099(21)00143-2
More recent work looks at the long-term dynamics under different annual vaccination strategies. We conclude "Our projections suggest that an effective booster campaign (in the over 50s) could generate manageable waves in 2022 before a long decline. However, weaker boosters that wane quickly can lead to large outbreaks in 2022. In the long-term, regular (annual) boosting of over 50s appears to be a necessary strategy if hospital admissions and deaths are to remain within manageable limits."
SAGE Links: https://www.gov.uk/government/publications/spi-m-o-insights-from-early-vaccination-modelling-9-december-2020
https://www.gov.uk/government/publications/university-of-warwick-covid-19-vaccine-impact-forecast-13-january-2021
https://www.gov.uk/government/publications/university-of-warwick-relaxation-of-npis-as-vaccination-proceeds-4-february-2021

RoadMaps

06/02/21	Roadmaps for Relaxation of NPIs. Moore & Keeling	SPI-M SAGE 80/81
29/03/21	Road Map Scenarios & Sensitivity. Keeling, Moore, Dyson, Tildesley & Hill	SPI-M SAGE 85
04/05/21	Road Map Scenarios and Sensitivity: Steps 3 and 4. Keeling, Dyson, Hill, Moore & Tildesley.	SPI-M SAGE 88
08/06/21	Road Map Scenarios and Sensitivity: Step 4. Keeling, Dyson, Hill, Moore & Tildesley.	SPI-M SAGE 92/93
06/07/21	Road Map Scenarios and Sensitivity: Step 4. Keeling, Dyson, Hill, Moore & Tildesley.	SPI-M SAGE
12/10/21	Projections of SARS-CoV-2 transmission and COVID-19 disease until June 2022. Keeling, Dyson, Hill, Moore & Tildesley.	SPI-M SAGE 96
Summary. Throughout 2021, there were a series of "Roadmap" documents that looked at the potential for relaxation of controls from the January lockdown to an absence of restrictions. Each of the above documents only refers to the final version of each of the six Roadmaps, whereas each document was the result of an iterated process, sharing preliminary results with the SPI-M-O group and SAGE before producing the final set of results.		

The initial document helped provide the forward projections enabling the selection of the time-frame over which relaxation would occur. The next four documents were produced before each Step in the relaxation process and generally provided confidence to the government that none of the step-changes would overwhelm health-care resources. The initial Step 4 document on 08/06/21 demonstrated the uncertainty in Step 4, due to the recent invasion of the Delta variant into the UK, and concerns that there may have been limited vaccine protection. The final document on 12/10/21, considered the longer-term dynamics.
Each of the documents shows increasing complexity and a deeper understanding of the roles of vaccination and human behaviour. The individual documents are available at:
A scientific summary document and retrospective examination of the Roadmap projections (including a comparison to subsequent data) is now published: Keeling, M.J., Dyson, L., Tildesley, M.J. Hill, E.M. & Moore, S. (2022) Comparison of the 2021 COVID-19 roadmap projections against public health data in England. *Nature Communications* **13**: 4924. https://doi.org/10.1038/s41467-022-31991-0
SAGE links: https://www.gov.uk/government/publications/university-of-warwick-relaxation-of-npis-as-vaccination-proceeds-4-february-2021
https://www.gov.uk/government/publications/university-of-warwick-roadmaps-for-relaxation-of-npis-6-february-2021
https://www.gov.uk/government/publications/university-of-warwick-roadmaps-for-relaxation-of-npis-18-february-2021
https://www.gov.uk/government/publications/university-of-warwick-road-map-scenarios-and-sensitivity-29-march-2021
https://www.gov.uk/government/publications/university-of-warwick-roadmap-scenarios-and-sensitivity-steps-3-and-4-5-may-2021
https://www.gov.uk/government/publications/university-of-warwick-road-map-scenarios-and-sensitivity-step-4-9-june-2021
https://www.gov.uk/government/publications/university-of-warwick-roadmap-scenarios-and-sensitivity-step-4-6-july-2021
https://www.gov.uk/government/publications/university-of-warwick-projections-of-sars-cov-2-transmission-and-covid-19-disease-until-june-2022-the-action-of-waning-efficacy-and-boosters-12-oc

Publications

First online: 24/09/2020 Published: 06/05/2021	Moore, S., Hill, E.M., Dyson, L., Tildesley, M., Keeling, M.J. (2021) "Modelling optimal vaccination strategy for SARS-CoV-2 in the UK" *PLoS Comp. Biol.* **17**(5): e1008849. https://doi.org/10.1371/journal.pcbi.1008849

Summary: In an early extension to the Warwick COVID model, we introduced a vaccinated class and a population with health conditions that are believed to have a significant impact on COVID-19 outcomes. At the time a number of different vaccine candidates were in development and the results from clinical trials were not fully available, leading to a large degree of uncertainty regarding the performance of these products. We therefore tested a range of efficacies (including reduced efficacy in the elderly) and three different types of vaccine each delivering a different level of protection.
This paper highlighted the importance of prioritising vaccination towards the oldest and most vulnerable in the population, as this generates the maximum reduction in deaths and other severe outcomes.

First online: 26/01/2021 Published: 18/03/2021	Moore, S., Hill, E.M., Tildesley, M., Dyson, L., Keeling, M.J. (2021) "Vaccination and non-pharmaceutical interventions for COVID-19: a mathematical modelling study" *Lancet Infectious Diseases.* **21**(6): 793-802. https://doi.org/10.1016/S1473-3099(21)00143-2
Summary: By combining models of vaccination with the methods of forwards projection, we considered the interaction between the relaxation of non-pharamaceutical interventions (NPIs) and the protection offered by the vaccine. This paper set the tone for unlocking the UK in 2021: Our modelled scenarios highlighted the risks associated with early or rapid relaxation of NPIs, stressing the need for slow release of control measures if large-scale waves of infection are to be avoided. We conclude that while the vaccines against SARS-CoV-2 offer a potential exit strategy for the pandemic, success is highly contingent on the precise vaccine properties and population uptake.	

First online: 10/06/2021 Published: 30/09/2021	Louise Dyson, Edward M Hill , Sam Moore, Jacob Curran-Sebastian, Michael J Tildesley, Katrina A Lythgoe, Thomas House, Lorenzo Pellis, Matt J Keeling. (2021) "Possible future waves of SARS-CoV-2 infection generated by variants of concern with a range of characteristics" *Nature Communications* **12**: 5370. https://www.nature.com/articles/s41467-021-25915-7
Summary: We used three mathematical models to examine the potential drivers of SARS-CoV-2 VOC epidemics in England. We found epidemiological trajectories for putative VOCs are wide-ranging and dependent on their transmissibility, immune escape capability, and the introduction timing of a postulated VOC-targeted vaccine. In particular, a variant that is less transmissible, but shows partial immune-escape, could provoke a wave of infection that would not be revealed until control measures are further relaxed.	

First online: 10/11/2021 Published:	Keeling, M.J., Thomas, A., Hill, E.M., Thompson, R.N., Dyson, L., Tildesley, M.J., Moore, S. (2021) "Waning, Boosting and a Path to Endemicity for SARS-CoV-2" *medRxiv.* https://doi.org/10.1101/2021.11.05.21265977
Summary: In many countries, an extensive vaccination programme has substantially reduced the public-health impact of SARS-CoV-2, limiting the number of hospital admissions and deaths compared to an unmitigated epidemic. The observed waning of vaccine efficacy over time suggests that booster doses may be required to maintain population immunity especially in the most vulnerable groups. Here, using data and models for England, we consider the dynamics of COVID-19 over a two-year time-frame, and the role that booster vaccinations can play in mitigating the worst effects. Although formulated for the Delta variant, this paper has key implications for Omicron.	

First online: 27/01/2022 Published:	Sam Moore, Edward M. Hill, Louise Dyson, Michael J. Tildesley, Matt J. Keeling (2021) The impacts of increased global vaccine sharing on the

	COVID-19 pandemic; a retrospective modelling study *medRxiv* DOI: 10.1101/2022.01.26.22269877
Summary: We use an age-structured model of SARS-CoV-2 dynamics, matched to national data from 152 countries, to investigate the global impact of different vaccine sharing protocols during 2021. We assume a direct relationship between the emergence of variants with increased transmissibility and the cumulative amount of global infection, such that lower global prevalence leads to a lower reproductive number within each country. We compare five vaccine sharing scenarios, from the current situation, through sharing once a particular within-country threshold is reached (e.g. all over 40s have received 2 doses), to full sharing where all countries achieve equal age-dependent vaccine deployment. Compared to the observed distribution of vaccine uptake, we estimate full vaccine sharing would have generated a 1.5% (PI -0.1 - 4.5%) reduction in infections and a 11.3% (PI 0.6 - 23.2%) reduction in mortality globally by January 2022. The greatest benefit of vaccine sharing would have been experienced by low and middle income countries, who see an average 5.2% (PI 2.5% - 10.4%) infection reduction and 26.8% (PI 24.1% - 31.3%) mortality reduction. Many high income countries, that have had high vaccine uptake (most notably Canada, Chile, UK and USA), suffer increased infections and mortality under most of the sharing protocols investigated, assuming no other counter measures had been taken. However, if reductions in vaccine supply in these countries had been offset by prolonged use of non-pharmaceutical intervention measures, we predict far greater reductions in global infection and mortality of 64.5% (PI 62.6% - 65.4%) and 62.8% (PI 44.0% - 76.3%), respectively.	

First online: 18/03/2022 Published: 22/08/2022	Keeling, M.J., Dyson, L., Tildesley, M.J. Hill, E.M. & Moore, S. (2022) "Comparison of the 2021 COVID-19 roadmap projections against public health data in England" *Nature Communications* **13**: 4924. https://doi.org/10.1038/s41467-022-31991-0
Summary: Here we present a retrospective analysis of our six Roadmap documents generated in 2021 to assess the likely impacts of future relaxation steps in England. In each case we directly compare results generated at the time with more recent public health data (primarily hospital admissions, but also hospital occupancy and death) to understand discrepancies and potential improvements. We conclude that, in general, the model projections generated a reliable estimation of medium-term hospital admission trends, with the data points up to September 2021 generally lying within our 95% projection intervals. The greatest uncertainties in the modelled scenarios came from estimates of vaccine efficacy, hampered by the lack of data in the early stages of the Alpha and Delta variant waves, and from assumptions about human behaviour in the face of changing restrictions and changing risk.	

Media

21/01/2021 Science Media Centre on Vaccination and NPIs

15/06/2021 Science Media Centre on Roadmap modelling

13/07/2021 Science Media Centre on Roadmap modelling

15/12/2020 Plus Magazine article, https://plus.maths.org/content/covid-19-vaccines-your-questions-answered

Module 2 of the UK Covid-19 Public Inquiry Request for Evidence under Rule 9 of the Inquiry Rules 2006
Reference for Request - M2/SAGE/01/SXM
01/04/2021 Plus Magazine article, https://plus.maths.org/content/vaccination-where-do-we-stand-and-where-are-we-going

Views on the success of the groups in which I have participated and lessons which should be learned.

As an early career researcher, and having no prior experience of working with any similar teams, I was generally overawed by the numerous individuals putting huge amounts of time and energy to contribute scientific advice to the pandemic response effort. Thanks to the efforts of those involved, as well as direction and support from an amazing team of secretariat, I believe that SPI-M-O in particular became a truly exemplary group given its limited resources and the pressures it was under. There were nevertheless a few factors which I believe had the potential to negatively impact the operation of SPI-M and the advice it was able to provide.

Data access caused issues for academics at numerous points throughout the pandemic. Mathematical models may only provide accurate forecasts when they are fitted to high quality and detailed data. As such it is of key importance that such data is made available to modellers in a timely and transparent manner. UKHSA/PHE held a large database of COVID data, though modellers only had access to partial information that was passed on at regular intervals. This meant for instance that, while trying to understand the impact of vaccine deployment, modellers had to rely on efficacy estimates provided by UKHSA. Fortunately, these proved to be reliable, but in the absence of a second opinion there is a risk that estimates will not be as robust as they otherwise might be.

As well streamlining access, I believe there is a requirement for developing a framework to prescribe the exact nature of data which should be collected and the manner in which it should be collated. There were frequently changes to the way that hospital data was counted, irregularities in reporting frequency and variances in how data was collected in different regions. This meant that modellers had to spend a significant proportion of time in data cleaning and attempting to recover the true values that represent the underlying processes, creating both delays and uncertainty. These issues were even more apparent when considering the differences in data formatting and reporting between the four nations, significantly limiting the capabilities to quickly extend forecasts to include the devolved nations.

Many individuals within the academic community worked wonders with incredibly tight deadlines and on very limited resources. Numerous early career researchers like myself volunteered to perform work for SPI-M-O and other SAGE subgroups, working very extended hours across evenings and weekends to provide essential analyses. Much of this work was most relevant in the moment and, in a fast-moving pandemic, it was difficult to find the time to format the research for academic publication before becoming overtaken by circumstances. Early career researchers are typically employed on short term contracts without a permanent position and rely on such publications for future employment. While there was a general feeling amongst academics of being happy to do anything that might help in any way possible, it is important that there is a strong system of support in place to ensure that expertise developed during the pandemic is not lost for the future.

I have similar concerns for the availability of future academic funding to ensure the UK maintains what is widely regarded to be a world leading modelling community that may be drawn upon in the future. The high quality of the SPI-M consensus documents and advice was the result of it bringing together numerous independent modelling efforts from across the UK. This enabled strong verification of results and the means to quickly identify any errors arising in individual models as a result of working to very tight time pressures. The extent to which this was the case was due in a large part to funding gained from UKRI to support post-doctoral researchers working on COVID-19 (supporting groups in Bristol, Cambridge, Exeter, Lancaster, Manchester, Oxford and Warwick through the JUNIPER consortium). Mathematical modelling was one of the few elements of advice that was open to detailed and deep public scrutiny, and hence has faced substantial criticism by those that have opposed the government approach to the pandemic. As a result it has been very sad to see some very negative attitudes directed towards scientists putting in large amounts of time on a purely altruistic basis, and unfortunately this commitment to providing results during the pandemic has not translated into funding success, despite the needs highlighted by our pandemic work. This is creating a danger that the step-change in methods that was required by the pandemic will be lost without further support.

Additional Materials

If required, I should be able to obtain copies of any of the submissions to SPI-M/SAGE that I have taken a role in producing. Usually the original copies will have been saved by the lead contributor of that research, and I understand that the SPI-M Secretariat should also have copies.