Institution: London School of Hygiene & Tropical Medicine (LSHTM)

Unit of Assessment: 2

Title of case study: Informing the UK response to COVID-19

Period when the underpinning research was undertaken: 2020

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed:
John Edmunds	Professor	23/6/08-present
Graham Medley	Professor	1/4/15-present
Adam Kucharski	Associate Professor	1/9/13-present
Rosalind Eggo	Associate Professor	6/5/15-present
Stefan Flasche	Associate Professor; Professor	19/4/12-present
Chris Bonell	Professor	15/11/04-present
Valerie Curtis	Professor	1/1/96-19/10/20
& associated research teams		

Period when the claimed impact occurred: January to December 2020

Is this case study continued from a case study submitted in 2014? No

1. Summary of the impact (indicative maximum 100 words)

Multidisciplinary research at LSHTM was at the forefront of informing the UK response to the COVID-19 pandemic. Researchers presented key mathematical modelling and social and behavioural science to underpin government decisions such as curtailing mass gatherings, closing schools and full lockdown. These decisions avoided an unmitigated epidemic scenario of 16 to 30 million symptomatic COVID-19 cases and 250,000 to 470,000 deaths, and prevented the NHS from being overwhelmed. By tracking the R number to assess the rate of transmission, LSHTM research informed the safe easing of restrictions, reinforced by positive messaging to encourage people to comply with the measures. This case study is UK-focused, but research products and educational resources were used worldwide.

2. Underpinning research (indicative maximum 500 words)

From the early days of the outbreak, researchers at LSHTM provided continuous evidence and expert advice to the UK COVID-19 response, drawing on extensive experience from studying previous disease outbreaks around the world. Due to the fast-moving nature of the pandemic and the need for quick decisions, they presented data and results to UK government advisory bodies in real time. Those intended for publication were made publicly available immediately in an online repository prior to peer review, before being accepted for publication in journals.

Modelling the epidemic and impact of restrictions
Staff in LSHTM's Centre for Mathematical Modelling of Infectious Diseases (CMMID) developed models to simulate the COVID-19 epidemic across 186 county-level administrative units of the UK. They modelled interventions by simulating changes to contact patterns; for example, for school closures, they decreased contacts made in schools to 0, with potentially increased contact between children and older adults to reflect grandparents providing more care.

To investigate initial characteristics of coronavirus in Wuhan, researchers combined a transmission model with data of COVID-19 cases in the city, and international cases that originated there, to estimate how transmission varied over time in January and February 2020. Estimates gave the first indication of the case fatality rate, and suggested that transmission declined in Wuhan during late January coinciding with travel restrictions and control measures, critically informing UK understanding of the potential threat (3.1).

The team also modelled the impact of non-pharmaceutical interventions in the UK on cases, deaths, and demand for hospital services, including the likely requirements for non-intensive care

unit (ICU) hospital beds and ICU beds over time (3.2). The team estimated that an unmitigated epidemic could result in 16-30 million symptomatic COVID-19 cases and 250,000-470,000 deaths. In this scenario, the NHS hospital and ICU bed capacity would be massively exceeded. A second scenario of shorter-term (1 week to 12 week) interventions, typically used to mitigate the burden of pandemic influenza and SARS, were found likely to be inadequate in the UK for COVID-19. ICU bed requirements would exceed availability by a factor of 10 to 30. In a third scenario, longer-term (1 year) programmes of social distancing and protecting the most vulnerable, plus periodic 'lockdowns' with stricter measures, had the potential to prevent exceeding NHS capacity. However, the team predicted these measures would likely need to last for at least several months.

LSHTM modellers, and sociologists led by Bonell, worked with University College London (UCL) researchers to predict the impact on transmission of schools reopening in summer 2020 (3.3). Scenarios included a full- and part-time rota system of alternating attendance, each within three testing scenarios reflecting various levels of contact tracing and testing. Alongside school reopening, the model included relaxing measures across society, on the assumption these would occur simultaneously. For each scenario, they estimated the number of new infections and deaths, as well as the reproductive number (R). This was complemented by modelling led by Eggo, which demonstrated the age-dependent effects of COVID-19 transmission, showing that susceptibility to infection in under 20s was around 50% lower than in adults over 20. Interventions aimed at children were therefore likely to have a relatively small impact on reducing transmission (3.4).

Tracking the R number
The LSHTM CoMix social contacts survey was designed to track the weekly reproduction number and regional differences through a representative sample of UK adults asked about the number of direct contacts they had on the day before each weekly analysis. Using these data, the team could predict the effect of social distancing measures, providing the first indication that the R number was driven below 1 during the first national lockdown as people observed the rules (3.5).

Influencing public behaviour
Combining modelling with social science insights provided evidence on measures where public behaviour was crucial to slowing transmission and reducing cases. Bonell and Curtis collaborated with experts at UCL, King's College London and Public Health England, to develop principles to inform interventions aimed at getting everyone to observe social distancing measures (3.6).

3. References to the research (indicative maximum of six references)

3.1 Kucharski AJ, Russell TW, Diamond C, Liu Y, Edmunds WJ, Funk S, Eggo R. 2020. Early dynamics of transmission and control of COVID-19: a mathematical modelling study. *The Lancet Infectious Diseases*. doi: 10.1016/S1473-3099(20)30144-4
(First online 28 January 2020 cmmid.github.io/topics/covid19/wuhan-early-dynamics.html)

3.2 Davies N, Kucharski AJ, Eggo R, CMMID nCov working group, **Edmunds WJ**. 2020. The effect of non-pharmaceutical interventions on COVID-19 cases, deaths and demand for hospital services in the UK: a modelling study. *The Lancet Public Health.* doi:10.1016/S2468-2667(20)30133-X
(First online 1 April 2020 cmmid.github.io/topics/covid19/uk-scenario-modelling.html)

3.3 Panovska-Griffiths, J. Kerr CC, Stuart RM, Mistry D, Klein DJ, Viner RM, **Bonell C**. 2020. Determining the optimal strategy for reopening schools, work and society in the UK: modelling patterns of reopening, the impact of test and trace strategies and risk of occurrence of a secondary COVID-19 pandemic wave. *Lancet Child and Adolescent Health.* S2352-4642(20):30250-9. doi: 10.1016/S2352-4642(20)30250-9

3.4 Davies NG, Klepac P, Liu Y, Prem K, Jit M, CMMID COVID-19 working group and **Eggo R**. 2020. Age-dependent effects in the transmission and control of COVID-19 epidemics. *Nature Medicine.* 26: 120-1211. doi: 10.1038/s41591-020-0962-9
(First online 24 March 2020 cmmid.github.io/topics/covid19/age_hypotheses.html)

3.5 Jarvis CI, van Zandvoor K, Gimma A, Prem K, CMMID COVID-19 working group, **Klepac P, Rubin GJ, Edmunds WJ**. 2020. Quantifying the impact of physical distance measures on the transmission of COVID-19 in the UK. *BMC Medicine.* 124. doi: 10.1186/s12916-020-01597-8 (First online 31 March 2020 cmmid.github.io/topics/covid19/comix-impact-of-physical-distance-measures-on-transmission-in-the-UK.html, weekly reports: cmmid.github.io/topics/covid19/comix-reports.html)

3.6 Bonell C, Michie S, Reicher S, West R, Bear L, Yardley L, **Curtis V**, Amlôt R, Rubin J. 2020. Harnessing behavioural science in public health campaigns to maintain 'social distancing' in response to the COVID-19 pandemic: key principles. *Journal of Epidemiology and Community Health*. 10.1136/jech-2020-214290

We believe this body of research meets the 'at least 2*' definition given its reach, significance and rigour.

4. Details of the impact (indicative maximum 750 words)

LSHTM was one of the leading UK academic groups working throughout 2020 on the COVID-19 pandemic to inform government action, continually presenting evidence to the Scientific Advisory Group for Emergencies (SAGE) and its subgroups. Its multidisciplinary analyses combining mathematical modelling with social and behavioural science were used by SAGE, the Chief Medical Officer (CMO) for England and the UK government Chief Scientific Advisor (CSA) to help formulate policy advice for the government to make evidence-based strategy decisions on virus control measures, including lockdowns, school closures and reopening, and NHS capacity.

LSHTM staff provided their expertise as members of SAGE (Edmunds, Medley, Bonell) and related sub-groups, including as of December 2020:
- the Scientific Pandemic Influenza Group on Modelling (SPI-M) (Kucharski, Davies, Eggo, Funk, Jit, Jombart, Medley (Academic Chair), Edmunds, Mathur, Rosello, Quilty, Clifford, Fearon, Knight)
- the New and Emerging Respiratory Threats Advisory Group (NERVTAG) (Edmunds)
- the Joint Biosecurity Centre Data Science Advisory Board (Medley)
- the Scientific Pandemic Influenza Group on Behaviour (SPI-B) (Bonell, Curtis)
- the Children's Task and Finish Working Group (TFC) (Eggo, Edmunds, Klepac, Medley) (5.1)

The UK Prime Minister, in thanking SAGE members ahead of the 50th SAGE meeting on COVID-19, recognised the '*extraordinary efforts of scientists… who have been instrumental to Her Majesty's Government response… SAGE has provided world-leading and rigorous scientific advice which has been invaluable to decision-makers*' (5.2). The CSA, in a letter of thanks to LSHTM's Director, highlighted the continuing contribution of LSHTM individuals to SAGE by name, recognising '*the decisive impact on the valuable scientific advice we have been providing to government through SAGE*' (5.3). Medley, Academic Chair of SPI-M, was made an OBE in October 2020 for services to the COVID-19 response (5.4).

Informing lifesaving restrictions
In parallel with Imperial College London models, CMMID models of a reasonable worst case scenario, exploring national-level impact of shorter duration interventions, curtailing sporting events and leisure activities, and repeated lockdown measures, were presented to SPI-M and SAGE in March 2020 (5.5). This cumulative body of evidence, combined with LSHTM's tracking of the rising R number, contributed substantially to the SAGE recommendation and UK government decision to instigate national lockdown on 23 March 2020, as well as to earlier decisions on interventions including school closures, case isolation, and curtailment of mass gatherings (5.6). This evidence was weighed by the government alongside competing political priorities influencing the timing of the decision. The evidence informed the decisions which led to quantifiable reductions in COVID-19 infections and deaths, and prevented the NHS from exceeding its capacity to cope. LSHTM CoMix data presented to SPI-M and SAGE demonstrated that the R number fell dramatically over the course of the UK lockdown from 24 March to 13 April (from 2.6 to 0.62) (3.5, 5.7), ensuring critical care capacity in NHS hospitals was not completely

overwhelmed. The modelling suggests that the interventions imposed on the UK public prevented the 16-30 million symptomatic COVID-19 cases and 250,00-470,000 deaths which were predicted in an unmitigated epidemic (3.2).

LSHTM staff also presented evidence on the impact of relaxing lockdown measures in April and May 2020, such as reopening schools and the optimal strategy for doing so (5.8). Together with Eggo et al's evidence demonstrating that susceptibility to COVID-19 was lower in younger age groups, R number tracking by LSHTM informed when it was safe to reopen schools, supporting the decision to partially reopen on 1 June in England.

Public behaviour and awareness
The principles co-developed with LSHTM social scientists were presented from SPI-B to SAGE in October 2020 (5.9) and underpinned communications from the government to the public on restrictions. SAGE endorsed the strategies for sustaining adherence to infection control behaviours emphasising collective identity and mutual care, and the messages were incorporated into communications to the public during the second UK national lockdown in November 2020.

Public engagement and sharing of expert knowledge were critical to increasing public knowledge of the virus and transmission, to improve compliance with restrictions and reduce case numbers. CMMID members made near-daily television appearances across the UK's major news channels from March 2020 onwards including the Today Programme, BBC News at Ten, Newsnight, Channel 4 News and Sky News, and provided regular expert comment to online and print news outlets. Medley served as a consultant to an e-book to educate children about coronavirus and control measures, working with illustrator Axel Scheffler (The Gruffalo). Published by Nosy Crow, *Coronavirus: a book for children* was a winner of the FutureBook Awards: Best of Lockdown in November 2020. The book was published under a creative commons licence, which allowed free sharing, and was viewed 1.5 million times on the Nosy Crow website and translated into 63 languages. The print edition raised GBP30,000 for NHS Charities Together (5.10).

LSHTM researchers also mobilised quickly to create a Massive Open Online Course, 'COVID-19: Tackling the novel coronavirus' hosted by FutureLearn, to help those interested in the outbreak response and its implications around the world. The free online course ran during March and April 2020 with 236,104 enrolments from 189 countries. The course was a recommended resource by the UK Government and NHS Health England (5.11).

LSHTM handwashing and hygiene experts including Curtis established the multi-partner COVID-19 'Hygiene Hub' in 2020 – a global initiative promoting sharing and learning among researchers and organisations. Between April and December 2020, the Hygiene Hub produced over 180 technical resources incorporating the latest evidence for the COVID-19 response. They were read online more than 64,000 times and LSHTM staff also provided tailored support to more than 140 organisations and governments in 60 countries (5.12).

5. Sources to corroborate the impact (indicative maximum of 10 references)

5.1 SAGE membership, meeting summaries and minutes, accessed at:
www.gov.uk/government/publications/scientific-advisory-group-for-emergencies-sage-coronavirus-covid-19-response-membership/list-of-participants-of-sage-and-related-sub-groups

5.2 Letter from Rt Hon Boris Johnson MP, UK Prime Minister, to Sir Patrick Vallance and Professor Chris Whitty expressing thanks to SAGE participants before 50th SAGE meeting. 6 August 2020.

5.3 Letter from Sir Patrick Vallance FRS FMedSci FRCP, UK Government Chief Scientific Advisor and Head of the Government Science & Engineering Profession, to Professor Peter Piot, expressing gratitude for the continued contribution of several named LSHTM academics to the work of SAGE. 11 June 2020.

5.4 The Queen's Birthday Honours List 2020. Accessed at:
www.gov.uk/government/publications/birthday-honours-list-2020-cabinet-office

5.5 Minutes of the fourteenth SAGE meeting on the Wuhan Coronavirus (COVID-19), 10 March 2020, and 'Adoption and impact of non-pharmaceutical interventions for COVID-19. MRC Centre for Global Infectious Disease Analysis, Imperial College, and CMMID, LSHTM' paper prepared for SAGE. Considered at SAGE 12 on 3 March 2020. Accessed at:
https://www.gov.uk/government/collections/sage-meetings-march-2020

5.6 The impact of adding school closure to other social distance measures. Davies, Kucharski, Eggo and Edmunds on behalf of the CMMID COVID-19 Modelling Team, LSHTM. 17 March 2020. Considered at SAGE 17 on 18 March 2020. Accessed at:
www.gov.uk/government/publications/the-impact-of-adding-school-closure-to-other-social-distance-measures-17-march-2020

The impact of banning sporting events and other leisure activities on the COVID-19 epidemic. Davies, Eggo, Kucharski and Edmunds on behalf of CMMID COVID-19 Modelling Team, LSHTM. 11 March 2020. Considered at SAGE 15 on 13 March 2020. Accessed at:
www.gov.uk/government/publications/the-impact-of-banning-sporting-events-and-other-leisure-activities-on-the-covid-19-epidemic-11-march-2020

5.7 The effect of social distancing on the reproduction number in the UK from a social contact survey. Report 2. Jarvis, van Zandvoort, Gimma, and Edmunds, LSHTM. 7 April 2020. Considered at SAGE 23 on 7 April 2020. Accessed at: www.gov.uk/government/publications/the-effect-of-social-distancing-on-the-reproduction-number-in-the-uk-from-a-social-contact-survey-report-2-7-april-2020

5.8 The impact of relaxing lockdown measures: 2. Davies, Kucharski, Eggo and Edmunds on behalf of the CMMID COVID-19 Modelling Team, LSHTM. 1 April 2020. Considered at SAGE 22 on 2 April 2020. Accessed at: www.gov.uk/government/publications/the-impact-of-relaxing-lockdown-measures-2-1-april-2020

Minutes of the thirty-first SAGE meeting on COVID-19, 1 May 2020, and paper on transmission and susceptibility in children prepared for SAGE, considered at SAGE 31 on 1 May 2020, accessed at:
www.gov.uk/government/collections/sage-meetings-may-2020#meeting-31,-1-may-2020

5.9 Minutes of the Sixty-third SAGE meeting on COVID-19, 22nd October 2020, and 'SPI-B: Positive strategies for sustaining adherence to infection control behaviours' paper prepared by SPI-B, considered at SAGE 63 on 22 October 2020, accessed at:
www.gov.uk/government/collections/sage-meetings-october-2020#meeting-63,-22-october-2020

5.10 Coronavirus: a book for children wins FutureBook award, accessed at:
www.thebookseller.com/news/pan-macmillan-nosy-crow-and-mr-bs-win-futurebook-awards-1226696

Letter from Kate Wilson, Managing Director, Nosy Crow and Author, Coronavirus: A Book for Children regarding contributions of Medley to children's e-book for understanding the pandemic.

5.11 COVID-19: Tackling the novel coronavirus. Accessed at:
www.futurelearn.com/courses/covid19-novel-coronavirus. Course listed as Health Education England's recommended resources for NHS staff, accessed at: www.telnorth.nhs.uk/portfolio-items/covid-19-tackling-the-novel-coronavirus/ and under UK government 'Coronavirus support for business from outside government'. 03 April 2020. Accessed at:
www.gov.uk/guidance/coronavirus-support-for-business-from-outside-government

5.12 Hygiene Hub, accessed at: hygienehub.info/en/covid-19
Figures on resources up until 18 Dec 2020